Water Rights and Related Water Supply Issues

Salt Lake City, Utah
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Preface

The papers included in these Proceedings were presented during the USCID Water Management Conference, held October 13-16, 2004, in Salt Lake City, Utah. The theme of the Conference, sponsored by the U.S. Committee on Irrigation and Drainage, was ***Water Rights and Related Water Supply Issues***.

An issue facing water users nearly everywhere is who has the right to use water when available supplies do not meet all the demands for that water. Since the earliest pioneers in the western U.S. first appropriated water for irrigation, water users, suppliers, governments and legal entities have endeavored to develop a system of water rights that can serve the public interest while also protecting vested rights, water quality and the environment. A key component of any discussion of water rights is how best to conserve, distribute and use limited supplies of water.

The Conference provided a forum to discuss the myriad issues related to water rights and the appropriation and distribution of water, including the application of technology.

Papers included in the Proceedings were accepted in response to a call for papers and were peer-reviewed prior to preparation of the final papers by the authors. The authors are professionals from academia; federal, state and local government agencies; water districts and the private sector.

The U.S. Committee on Irrigation and Drainage and the Conference officers express gratitude to the authors, session moderators and participants for their contributions.

The U.S. Department of the Interior, Central Utah Project Completion Act Office, sponsored the Conference Proceedings and this support is acknowledged with appreciation.

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THE SACRAMENTO VALLEY WATER MANAGEMENT PROGRAM: RESOLVING A CALIFORNIA WATER ISSUE THROUGH PARTNERSHIP RATHER THAN CONFLICT

Kirk C. Rodgers[1]
John F. Burke[2]
Betty Riley-Simpson[3]

ABSTRACT

For over 40 years, the State of California has struggled to develop the appropriate water quality standards for the Sacramento-San Joaquin Delta and to determine which water sources are required to meet those standards. This struggle has involved years of contention and litigation and has been elevated to the United States Supreme Court. In order to provide ecosystem protection for the Bay-Delta Estuary, representatives from the State and Federal governments and urban, agricultural and environmental interests agreed to implement a Bay-Delta protection plan through the California State Water Resources Control Board (SWRCB). The agreement referred to as the Bay-Delta Accord (Accord) was signed December 1994. The Accord set standards to meet the water quality objectives.

On May 22, 1995, the SWRCB adopted the Water Quality Control Plan for the San Francisco Bay/Sacramento San Joaquin Delta Estuary (WQCP). The WQCP contains the current water quality objectives. Phases 1–7 of the water rights proceedings involved the San Joaquin Valley and other Delta issues and resulted in D-1641 and Order WR 2000-10, which contain the current water right requirements to implement the Bay-Delta flow dependent objectives.

Phase 8 of the Bay-Delta water right hearings would have addressed the Sacramento Valley water user=s responsibilities. In Phase 8, the State and Reclamation claim that certain water rights holders in the Sacramento Valley must cease diversions or release water from storage to help meet Delta water quality standards. Sacramento Valley water users contend their use has not contributed to water quality problems in the Delta and so, as senior water right holders and water users within the watershed and counties of origin, they should not be responsible for meeting these standards. The Phase 8 process would ultimately determine which entities and individuals would be responsible for

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meeting the water quality standards. The California State Water Project (SWP), operated by the Department of Water Resources (DWR) and the federal Central Valley Project (CVP), operated by the Bureau of Reclamation, agreed to voluntarily meet the water quality standards pending the SWRCB's water rights proceedings to determine the final responsibility for meeting the water quality standards.

The SWRCB encouraged parties to resolve among themselves the responsibilities for meeting the objectives in the 1995 Bay-Delta Plan and to bring their joint proposals for establishing responsibilities to the SWRCB for approval.

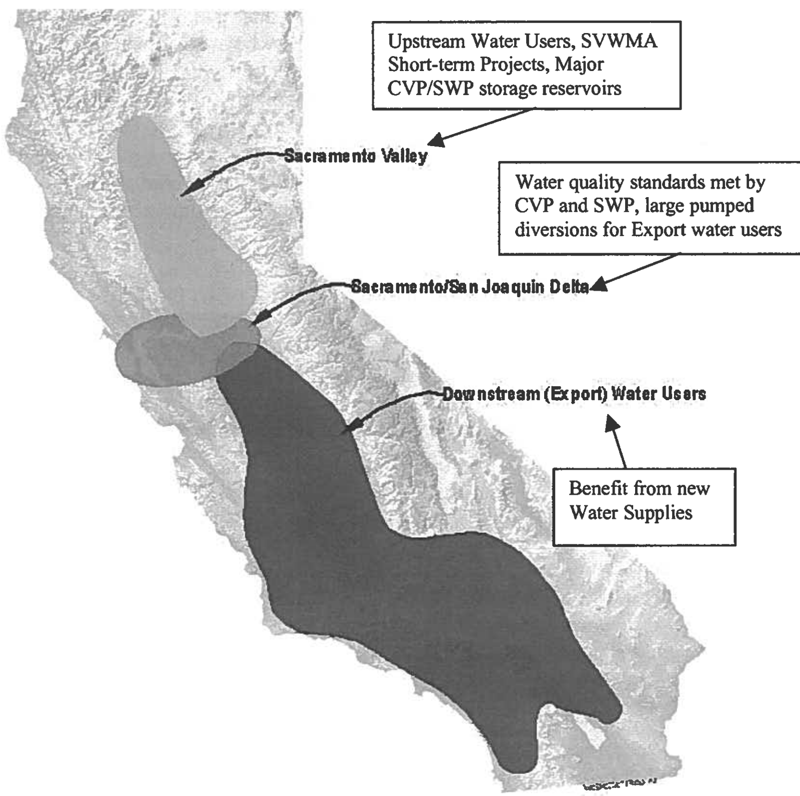

Figure 1. Location of Key Components of SVMWA

THE SETTLEMENT PROCESS

SWRCB Issues Stay for Phase 8: On January 11, 2001, DWR, Reclamation, some of their water supply contractors and the members of the Northern California Water Association approached the SWRCB at a workshop with a draft of an agreement among these parties. The SWRCB then stayed Phase 8 based on the April 2001 settlement agreement among DWR, Reclamation, the State Water Project contractors and the Northern California Water Association, and the San Luis and Delta-Mendota Water Authority.

Parties Develop Short-term Workplan: During the stay period the parties completed a Short-term Workplan which identified integrated water management projects that will enhance the Upstream and Export Water Users ability to use their existing supplies, meet future water needs, and enhance water management flexibility. The Short-term Workplan, completed in October 2001, serves as the technical basis for implementation of the short-term projects that will provide the water that facilitates the settlement.

Statement of Principles: The parties executed a Statement of Principles for the implementation of the Sacramento Valley Water Management Program (SVWMP) in December 2001. These principles served as a basis for a water rights settlement agreement regarding Phase 8 of the SWRCB's process to implement the 1995 WQCP. In the Statement of Principles, the Upstream Water Diverters agreed to develop up to 185,000 acre-feet of new water that could augment the CVP and SWP water supplies. The SVWMP will implement the goals and objectives of the settlement agreements. The SVWMP will be implemented in two phases, a short-term phase and a long-term phase. Negotiation of the Short-Term Settlement Agreement was already underway.

Short-Term Settlement Agreement: March 2003, these same parties executed the Short-term Settlement Agreement. The Short-term Settlement Agreement is an interim settlement to accomplish short-term objectives while work proceeds on development of the Long-Term Settlement Agreement. The objectives of the Short-Term Agreement are to:

- Meet the flow-related objectives of the 's D-1641, thereby avoiding litigation of Phase 8 issues
- Begin implementing and accomplishing the principles and goals of the Stay Agreement.
- Implement the Short-Term Projects, owned and operated by the Upstream Water Users, in a manner that will not adversely affect currently available supplies of the CVP and SWP and will: (1) meet water demands in the Sacramento Valley, (2) provide at least 92,500 and up to 185,000 acre feet of water to augment CVP and SWP supplies during certain water year types

- Develop and implement monitoring programs that will assist in evaluating the performance of the Short-Term Projects.
- Establish milestones for the Long-Term Workplan and a Long-Term Settlement Agreement that will enable parties to fully meet the terms of the Stay Agreement
- Provide procedures to implement remedial actions as necessary to meet these objectives.
- Jointly secure funding for Program implementation

Pursuant to Short-term Settlement Agreement, Upstream water users will provide Reclamation and DWR up to 185,000 acre-feet of water by pumping groundwater in-lieu of taking their surface diversions and also by reoperation of reservoir water supplies. In exchange, SWP and CVP will meet the 1995 WQCP requirements. Some of the short-term projects or actions in the SVWMP include refurbishing existing or installing new wells, system improvements such as canal lining and tailwater recovery systems, etc. As a result of the settlement agreements, the SWRCB dismissed Phase 8 of the Bay-Delta hearings in January 2003.

Table 1. Water Made Available Annually by SVWMA

Comparison of Blocks				
Blocks	**Percent**	**Acre-feet**	**Purpose**	**Cost**
Block 1	50%	Up to 92,500	Purchase	\$ 50 Above Normal \$ 75 Below Normal \$100 Dry \$125 Critically Dry
Block 2	50%	Up to 92,500	Water Quality	O&M Cost of Source
Total	100%	Up to 185,000	Settle Phase 8	Averaged at \$50/AF
If DWR or Reclamation elect to call for all or a portion of Block 2 water, they will be required to purchase an equal amount of Block 1 water if that water is available.				

Managing the Settlement and Implementation of the Program

The Short-Term Settlement Agreement established a Management Committee and a Technical Measurement and Monitoring Committee.

Management Committee: The Management Committee provides oversight for implementation of the Program, ensuring that the Short-Term Projects are implemented consistent with the provisions of the Short-Term Settlement Agreement. The Management Committee consists of 14 voting members, with an equal number of Upstream Water Users and the Downstream Water Users. Reclamation and DWR are included among the Downstream Water Users. Any decision of the Management Committee requires a majority of both Upstream and Downstream voters. The Downstream majority must include the votes of Reclamation and DWR. The Management Committee establishes additional committees or work groups, as necessary. To date the Management Committee has established an Environmental Documentation Team, a Long-Term Workplan Team, and a Reservoir Storage and Refill subcommittee of the TMMC.

Technical Measurement and Monitoring Committee (TMMC): The TMMC establishes procedures to determine if projects are meeting objectives of the agreement. TMMC also will prepare an Annual Operating Plan, develop monitoring programs, analyze data from the monitoring, and resolve technical disputes, all subject to the approval of the Management Committee.

SHORT-TERM WORKPLAN DEVELOPMENT

The SVWMA established a process through which the parties are collaborating in development and implementation of a variety of water management projects to expand the availability of Sacramento Valley water resources in ways that will achieve the goals of the agreement: meet inbasin needs, help meet requirements of the 1995 Water Quality Control Plan, as well as additional needs of water users reliant on Delta water exports. A key element of the SVWMA is the development of a short-term workplan for examining candidate projects that could meet the goals of the agreement. Short-term projects are those that could potentially be implemented within one or two years. A Management Team and a multi-agency, interdisciplinary technical Workplan Development Team (WDT) were established to produce the Short-term Workplan.

NCWA issued a solicitation for potential projects throughout the Sacramento Valley on May 7, 2001. The focus of this effort was to encourage willing participants at the water user level to bring forth ideas for projects that met the basic goals of the agreement. This "bottom up" approach to participation was viewed as a key to overall success of the SVMWA. Numerous proposals were received, and the WDT did detailed technical evaluations for each, focusing on feasibility, costs, and potential benefits to water supply, environmental values and water quality. Eventually, 45 projects were included in the Short-term Workplan. The projects were spread geographically across eight sub-basins of the Sacramento Valley. The 45 projects were then grouped into four major categories (see Table 2).

The WDT developed initial screening criteria to guide the selection and evaluation of each proposed project. The criteria were:

- Projects assist meeting following goals
  - Provide water for upstream demands
  - Improve water quality and export supply

  - o Provide environmental Benefit
  - o Provide flexibility for operations

- Projects result in a minimum of adverse environmental impacts
- Institutionally feasible
- Technically feasible
- Ready for implementation in 1-2 years
- No environmental permitting fatal flaws

Significance of Hydrologic Sub-basins to Short-term Projects

Proposed projects fell within the eight identified sub-basins of the Sacramento Valley (see Figure 2). The sub-basins generally represent hydrologic and groundwater aquifer boundaries. To maximize the effectiveness and economy of the overall program, it was recognized early in the process that the relationship among projects within sub-basins could be a key. A goal was set to develop a mix of projects within each sub-basin that would maximize benefits and minimize impacts. Evaluating projects within sub-basins is the approach historically used by DWR in development of the Sacramento Basinwide Water Management Plan. Evaluation by sub-basin was also useful in identifying how proposed projects could help meet future water needs within the sub-basins for which data was available.

Table 2. Projects Evaluated in Short-term Workplan

Category	Number of Projects	Characteristics
Surface/Groundwater Planning	12	Monitoring, Area-wide Inventory or Assessment
System Improvement	13	Canal Lining, Tailwater Recovery, or Improved Operations
Water Management	14	Facilities/Programs to Use and Monitor Surface Water and Groundwater
Institutional	6	Transfers or Regulatory Hurdles

Results of Evaluation of Short-term Projects

The Short-term Workplan included evaluations of 45 projects, falling into the aforementioned four categories and eight sub-basins of the Sacramento Valley. The water management projects collectively were estimated to yield up to 185,000 acre-feet of new water supplies. System improvement projects could provide 100,000 acre-feet in benefits, mostly in the form of re-routed flows, and so are not generally considered new water supplies. Figure 2 summarizes the potential benefits from water management and system improvement projects.

There is considerable flexibility possible in the operations of many of the projects, so that the benefits achieved in particular years may vary in response to hydrologic conditions, or the needs of the in basin users or the downstream signatories to the SVWMA. For example, a water management project in the Feather/Butte Basin could be operated to supplement instream flows, or to transfer water to assist in meeting Bay-Delta water quality requirements.

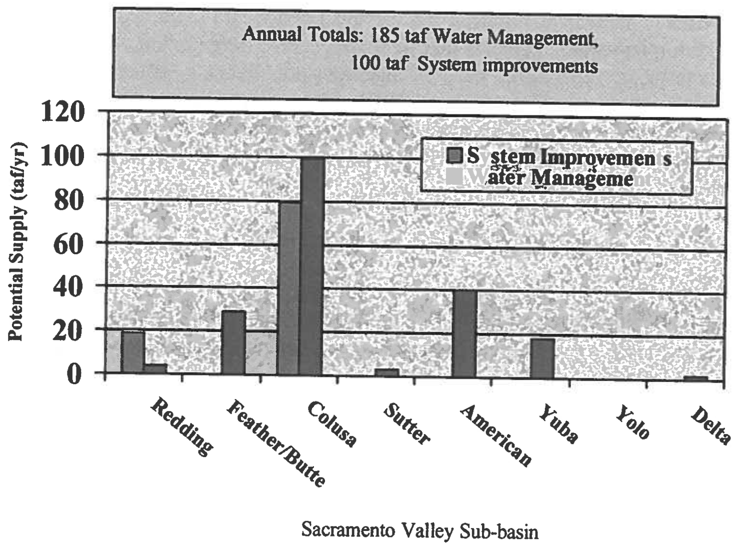

Figure 2. Estimated Benefits of Short-term Projects by Sub-basin

Cost estimates were a part of the evaluation performed for each project. Figure 3 displays the estimated cost of the projects by sub-basin. The total estimated cost is $87 million, with the categories of projects as follows: Water Management-$40 million, System Improvement- $31 million, Planning- $16 million.

Implementation Issues

Many of the Short-term projects have issues associated with them that will need resolution prior to successful implementation. For example, canal-lining projects may affect adjacent wildlife habitat, or existing downstream uses. Groundwater development projects may be constrained by potential impacts on adjacent surface and groundwater resources. State and federal listed species inhabit many of the project areas, and will require consideration and consultation. Air quality protection and possible growth inducement have also been noted as issues of concern in public input to date.

Role of Short-Term Implementation Agreements

The Short-Term Settlement Agreement requires that each Short-term project will be implemented based on an agreement between the local sponsoring Upstream water user(s), Reclamation and DWR. These agreements will govern when and how water is made available from each project and what monitoring programs must be implemented. Projects that involve reservoir reoperation will include criteria to insure refill of reservoir storage does not adversely affect Reclamation or DWR's operation of the CVP and SWP. Short-Term implementation agreements will conform to the overall settlement agreements, and will include provisions describing obligations of the parties in the event the Long-Term Agreement is not executed.

Division of Water Made Available by Upstream Water Users

In July 2003, as part of a comprehensive proposal to more closely integrate the operations of the CVP and SWP, Reclamation and its CVP contractors agreed with DWR and its SWP contractors to apportion the water provided by the Short-Term phase of the SVWMP, 60% for the SWP, and 40% for the CVP. This proposed agreement, called the Project Integration Proposal, also addressed additional conveyance, storage, and water supply commitments for the benefit of the CVP and SWP. It also identified new and enhanced coordination protocols, and settled some technical coordination issues associated with new project features and regulatory criteria that have been introduced since the COA was first executed in 1986.

Funding

An estimated $87 million is required for the capital costs of the short-term projects. Some projects have already been partially funded through state issued bonds (Proposition 13), the CALFED Water Use Efficiency Program, or AB303. Most projects are still unfunded, though. The SVWMA Management Team is working on sources of project funding and potential cost sharing. Availability of funds and the distribution of project benefits will ultimately drive project funding decisions.

Relationship to CALFED Program

The parties to SVWMA will implement the agreement consistent with CALFED's goals. In 2000, the CALFED Record of Decision recognized the role of regional initiatives towards successfully meeting CALFED's goals for environmental restoration, water quality, and water supply. SVWMA projects will likely depend partly on CALFED for some public funding, although funding decisions will necessarily be made case-by-case. Some of the environmental benefits expected from SVWMA projects that are consistent with CALFED goals include: increased flows or changes in timing of flows to assist meeting Bay/Delta water quality needs, reduced diversions during critical life stages of fish, augmented streamflows for fishery habitat, increase in supplies available for the Environmental Water Account.

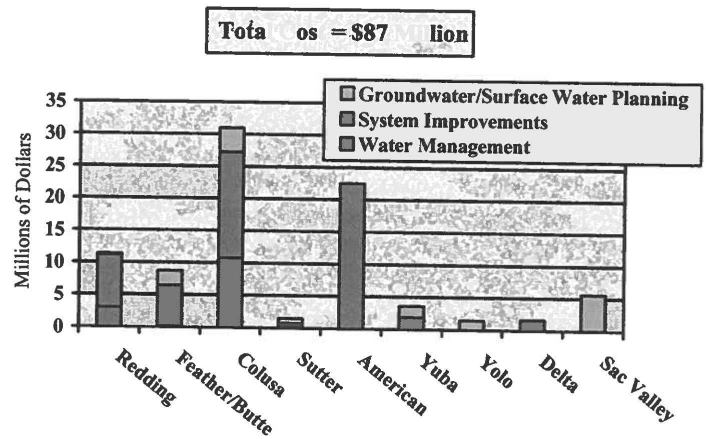

Figure 3. Cost of Short-term Projects by Sub-basin

Environmental Documentation

An EIR/EIS will be produced to address the benefits and impacts associated with the Short-term projects. Bureau of Reclamation and DWR are lead agencies for NEPA and CEQA, respectively. Project proponents will act as responsible, or potentially co-lead agencies. The EIR/EIS will reference the CALFED programmatic EIR/EIS. No water will be transferred from SVWMA projects pending completion of the EIR/EIS, scheduled for June, 2005.

Outreach

The parties to SVWMA have conducted an ongoing outreach program to inform and solicit input from other agencies, environmental interests, and the public about the program objectives, project status and time lines. Additionally, the SWRCB order to stay Phase 8 called for public workshops every six months, to facilitate public participation.

LONG-TERM AGREEMENT

The Short-term Settlement Agreement may extend to 2014, unless replaced earlier by a Long-term Settlement Agreement. The parties agreed to complete a Long-term Workplan by March 31, 2005. Long-term projects will be implemented under contracts exceeding the ten-year term of the short-term projects. While it is anticipated that some of the proposed short-term projects will continue as a part of the Long-term, it is expected that a Long-term agreement will depend on the construction on one or more of the proposed CALFED storage projects: either enlarged Shasta Dam, Sites Reservoir, or other similar North-of-Delta surface storage reservoir.

CONCLUSION

Proceeding with the Sacramento Valley water rights review in the SWRCB's Phase 8 proceedings would certainly have been a lengthy and contentious effort. With subsequent litigation and judicial review the process could have taken ten years, with outcomes uncertain for all the parties involved. Meanwhile, the conflict would have created barriers to progress on CALFED solutions to water management issues. The idea of a partnership and collaboration that reinforces common goals and interests has become an increasingly attractive alternative to protracted regulatory and legal battles among diverse water interests in California. The SVWMA is a settlement that invests in a solution intended to bring increased water management flexibility, efficiency, and reliability for local users in the Sacramento Valley, and to the customers of the CVP and SWP. Reclamation views the SVWMA as a significant step toward meeting current and future water supply needs.

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CONSENSUS BUILDING AS A PRIMARY TOOL TO RESOLVE WATER SUPPLY CONFLICTS

MaryLou M. Smith[1]

ABSTRACT

The allocation of limited supplies of water for multiple uses in the western United States is increasingly difficult. Stakeholders have diverse and seemingly irreconcilable needs, with many deep-rooted opinions on how the water should be allocated. A complex system of water rights and the regulations of multiple government agencies add further complications.

The U.S. Department of the Interior has deemed the issue serious enough to undertake *Water 2025: Preventing Crises and Conflict in the West*, to "speed up the resolution of water supply problems and ensure that the solutions are balanced and durable." How will solutions be found? Are more technological solutions needed, or better application of the technological solutions already available? Or are solutions more likely to be found in the arena of resolution of conflict among stakeholders laying claim to the water? How can the public be brought onboard in a meaningful way, when the issues are so complex? Do models used in the past provide the framework through which resolution can be achieved? Does legislative action and/or public referendums help or hinder?

This paper proposes that those responsible for making decisions about water supply allocation should consider creative consensus building processes their primary tool, not a peripheral one. Such processes should take the place of adversarial debate and litigation which often leads to mediocre results and a discouraged, disenfranchised public. Research dollars should be allocated to explore emerging collaboration techniques and to formulate and test state of the art consensus building technologies. Consensus built solutions should replace 1) adversarial debate on the part of legislative bodies and 2) voting by the public via the referendum process. The State of Colorado's current experience with a statewide water supply initiative following a failed public referendum is discussed as a case study.

Referendum A—Background and Outcome

Referendum A, a 2003 ballot initiative in Colorado to provide a line of credit for water development projects, was soundly defeated by a 2 to1 margin, despite a period of prolonged drought combined with the state's highest growth rate ever. Voters and water leaders interviewed cited the primary reason for defeat to be the

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measure's lack of specific projects to be funded. Others, including many in the water industry who favor increased storage, did not see the need for this referendum because they believe the issue is not getting money for water storage, but getting water storage proposals through a complicated series of approvals, primarily environmental, something the measure did not address.

Environmentalists voted against the measure believing that conservation is sufficient to solve the state's water supply problems so further storage is not needed, or because they favor a balanced approach that ties serious, long-term water conservation measures with storage solutions crafted to minimize large disruption of ecosystems. West Slope farmers and politicians voiced concern that east slope needs would, under the terms of the Referendum, take priority over their needs without proper mitigation of the effect on their communities.

In 2002, attempts to move permanent storage forward as a critical solution were launched during two different legislative sessions. The first attempt failed, but the second passed both the House and the Senate after provisions were included to address concerns related to conservation and in-stream flow as well as mitigation of negative effects of water infrastructure projects on west slope communities. This legislation, because of the funding mechanism required, had to go before the voters in the form of a referendum.

Before the election, Denver Post pollster Floyd Ciruli wrote: "Lawmakers hoped the referendum would prompt interest groups to work together to find a solution, but it could backfire. This is really a political exercise on building for the future. If the referendum fails, it will be self-defeating. It could set back reaching a consensus for many years." Indeed, it appears that the most obvious outcome of Referendum A is that it seems to have further polarized stakeholders.

Water Buffaloes

Some believe Coloradoans voted against Referendum A to avoid a return to the heydays of the state's "water buffaloes--" a handful of giants such as Glenn Saunders, John Fetcher, and Wayne Aspinall who, according to the Denver Post, earlier "worked political deals to snare huge chunks of federal money for large dams and reservoirs." Their foresight and courage is said to have made possible today's Colorado—large expanses of irrigated farms and Front Range cities. No one doubts the contribution of these men, though some, following the logic of writers such as Donald Worster in *Rivers of Empire*, believe the region would have been better left in its natural form. In fact, Worster proposes that large projects by the Bureau of Reclamation were intended more to line the pockets of industrialists with agricultural holdings than to serve the public good.

An April, 2004 feature in the Denver Post pointed out that the days of water buffaloes appear to be over, considering that "not one reservoir or dam has been built in Colorado in 40 years." The Two Forks project proposed for the South

Platte River cost taxpayers forty million dollars before it died at the planning table in 1990. The Post article quotes a new generation of water thinkers, such as former assistant state attorney general Melinda Kassen, who says "The kind of projects that get built today are… smaller, faster, cheaper, (with) more conservation, more cooperation."

In his article *The Water Divide in Colorado*, pollster Cirruli summarizes key differences of opinion about Colorado water shortages. He says the issues revolve primarily around out of basin diversions and amount of mitigation required, the efficacy of new storage structures, the potential for reliance on conservation and reuse strategies, and the use of agricultural water for municipal and industrial needs. He talks about a new political environment of water which he calls "post-Two Forks thinking." He says that economic development executives, water policy makers, municipal leaders and others are talking more seriously recently regarding methods to bridge differences of opinion. But, he says "only when actual projects are proposed will it be clear if the willingness to compromise is real."

Where are the visionaries who will champion new solutions with the foresight of the last century's water buffaloes? Where are the movers and shakers with the foresight to capitalize on the various needs/values/viewpoints and carve out solutions which are not black, not white, not even gray, but maybe chartreuse or purple?

Statewide Water Supply Initiative

Governor Bill Owens, in his January 2002 state of the state address, directed the Colorado Water Conservation Board (CWCB) to launch a "statewide water supply initiative." SWSI, (pronounced SWAH-zee) was to be a forum for diverse water use interests. The Department of Natural Resources (DWR) hired a consultant, Camp Dresser McKee (CDM), to lead diverse stakeholders in each of the state's eight basins to assess: What water is available? What are the demands? What are potential alternatives for meeting demand? Basin roundtables were established to receive and discuss results of the work of DNR and CDM, and to narrow down possibilities into a set of proposed alternatives for CWCB to present to the legislature.

Colorado Water Congress Panel: What Now, After Referendum A?

Convened by Colorado Water Congress in Denver in January 2004, selected state water leaders were asked "What Now, after Referendum A?" Though almost everyone expressed interest in dialogue, the only mechanism cited for such was SWSI. Here are some representative comments:

Don Ament, Colorado Commissioner of Agriculture, spoke of the need for "a new collaboration and a cooperative effort."

Peter Binney, Director of Utilities, City of Aurora, alluded to a successful agreement between Aurora and the Arkansas Valley, and said "I suggest that our legislature start thinking about intrastate compacts, whether they be between basins or between users of the past and users of the future."

Reeves Brown of the West Slope's Club 20 said : "The biggest lesson we learned from Referendum A was we need to build consensus before we build proposals." We need to "get beyond the C words of conflict, courtrooms, and condemnation."

Jo Evans, environmentalist, said "We don't reach consensus when the people are at the table primarily to see that their ox is not being gored."

Bob Ewegen, Denver Post: "I think Referendum A was a constructive dialogue. I supported Referendum A because we need to change the attitude, the dialogue, the way in which water is discussed in this state. We need to at least bring things like win/win solutions to the table."

Jim Martin, Natural Resources Law Center, CU Law School in Boulder: "Referendum A was not a dialogue. It was whatever the opposite of dialogue is. What we need is a very broad based, comprehensive, careful, patient dialogue in this state about water. We have to refrain from the sort of heated rhetoric and blame game we have been guilty of in the past. And we need to think more carefully about the others sides' perspectives, needs and wants and try to find some sort of way down the middle that really does provide an equitable solution and a vision for a sustainable Colorado. We need to get more serious about finding a way in which we can create a forum in which all the stakeholders are not only invited, but feel comfortable and capable of participating fully and effectively. That's different than just putting everyone in a room together. Unless we do this, we're going to continue to spin our wheels on this issue because this is such a difficult and complex issue that goes to the very heart of what most of us hold dear."

Frank Jaeger, Parker Water and Sanitation District: "I don't want to see a hundred more bills come across my desk. I've got a stack that thick of water bills that don't mean a hell of a lot to me other than half of them will injure me and the other half will move the fulcrum in my direction. We don't need a plethora of bills that put power on one side of the table or the other, we need business deals, deals which require that both sides walk away feeling comfortable with what happened."

Harold Miskel, Colorado Water Conservation Board, introduced a "set of C words we can work toward: cooperation, collaboration, consensus, communication." He said, "We need to have dialogue that gets to what people are really feeling, what's at the root of their values. We need to be responsive to the concerns of the people who are impacted by proposed projects. We need to build understanding from the bottom up, understanding of what the needs are, what the resources are, what the concerns and issues are, and then start talking about what the possible options are to take care of these issues and concerns. The only way is for folks to come to the table and talk about these things. That's what the Statewide Water Supply Initiative (SWSI) is all about."

Wally Stealey, Southeast Colorado Water Conservation District, and the most outspoken panel member said, "We're beginning to understand that Harold Miskel's C words have a much greater impact than we thought. But we need real consensus, real compromise, not a definition of compromise that says 'you take, I give.' It must truly be consensus of the citizens of Colorado."

During this panel discussion several stakeholders pointed out that "we need dialogue." But instead, everyone just gave their fifteen minute spiel and participated in a question and answer session afterward. If dialogue is desired, when will it begin? Will Colorado Water Congress convene the next discussion around a consensus building format instead of a panel?

Where is SWSI Now?

At the May, 2004 meeting of the CWCB, DNR staff and CDM consultants reported on completed work related to supply and demand findings, and stated that the next round of basin roundtable activities would focus on generation of alternatives. Alternatives will be proposed by the consultants, and stakeholders will discuss them, presumably coming to consensus about which ones will be presented to the legislature in November.

Also presented were results of an objectives weighting process in which basin roundtable participants were asked to weigh agreed upon objectives in a forced choice manner. Slides were shown depicting for each basin how different interest groups weighed the various objectives. As one might expect, the results fell along interest lines. Agriculture stakeholders ranked "meeting agriculture demands" the highest, while environmental stakeholders ranked highest "providing for environmental enhancement." CDM plans to track how participants representing different interest groups (stakeholders) score different proposals brought forth as compared to their stance in the objectives weighting process, stating that the process is supposed to lead to a "forum for dialogue and understanding."

One CWCB director, Raymond Wright, expressed discouragement at the findings of the objectives weighting process. Regarding what the weighting process showed in terms of stakeholders weighing objectives according to their own bias, he said, "I don't like this. It implies a high degree of divisiveness." He said that he thinks discussions can be fruitful, however, if they are properly structured and "if stakeholders are encouraged to think win-win." How the objectives weighting process will lead to a forum for dialogue and understanding, as intended, is yet to be seen.

Part of the SWSI process has been to solicit public input. At the February meeting of the SWSI South Platte Roundtable, environmentalists from more than a dozen organizations took advantage of the public input time to read prepared statements. The result was not dialogue, but simply a series of monologues—an airing of views.

Will SWSI bring diverse interests together? Will roundtable participants be successful in hammering out mutually acceptable proposals to take to the legislature? What will the legislature do with the proposals brought forth by SWSI? Are state legislators, CWCB, and those involved in SWSI putting sufficient emphasis on the process by which alternatives are to be assessed and consensus derived?

<u>Western Governors on Water Issues Collaboration</u>

One source which would seem to be important to those interested in serious consensus building at the state level is the proceedings of a 2002 conference chaired by then Governor of Oregon, John A. Kitzhaher, M.D. In his forward to *WaterShed Solutions: Collaborative Problem Solving for States and Communities* Kitzahaher asserts that collaborative watershed partnerships cannot replace legal and regulatory tools but they can become the vehicle through which those traditional tools can be more successfully applied. This valuable document outlines important points about collaboration in watershed matters including that collaboration

- reduces conflict and litigation which often results in unsatisfactory, narrow decisions that don't address underlying problems.
- can turn apparently inflexible federal or state mandates into opportunities
- provides an alternative way of approaching problems that avoids the gridlock often associated with traditional governmental approaches

Conferees agreed that states should appropriate funds for collaborative processes, provide high level training to all levels of public officials and private stakeholders in fundamentals of collaboration, develop demonstration projects to showcase collaboration, and request universities to conduct research on collaborative problem solving.

Drought in the West: Can Consensus and Collaboration Make a Difference? is a special report which came out of the 2002 annual meeting of Council of State Governments-West, which provides a platform for regional cooperation among the legislatures of the 13 western states. The report includes points made by representatives from Montana-based Western Consensus Council who talked about "replacing traditional procedures used to resolve conflicts in the public arena with collaborative models for problem solving." Asserting that traditional procedures result in gridlock, impasse, and skyrocketing legal fees, they presented a table of actions that can be taken within a legislative context to foster collaborative procedures, the most radical of which is "by instituting the collaborative process through statute."

Southern Alberta (Canada) Experience

Many who deal with water issues in the west have been fascinated by the recent experience of the Southern Alberta (Canada) Water Users Group in which consensus was reached despite long odds during their drought of 2000. The group has been highly praised and has earned numerous awards as a result of their achievement. When asked what it took to bring water users to the table to develop a win-win solution, two factors rise to the top. The first is that of crisis. Something had to be done or large numbers of irrigators would lose their crops. The second factor appears to be that the largest user and the user with the most power (the St. Mary River Irrigation District) willingly gave up some of their rights to benefit others, so that legalities were overridden for the period of the drought. Does this example have lessons for the rest of us?

What Did Referendum A Tell Us about Voters?

Some believe Referendum A did not pass because the public is not well-educated about water issues. An alternative view could be that the public voted against the measure because they *are* educated and they want a full view of the situation so they can make educated decisions. Is it possible that by voting no to Referendum A and leaving the state without a solution to its significant water supply problems, the public was not being blind to realities, but were basically saying they want meaningful choices, not black and white, pieced-together solutions? Is it possible voters saw the bill as basically a storage solution with environmental and western slope mitigation concessions tacked onto it as an insincere attempt to bring along the "other side?"

Many voters interviewed expressed that they felt disenfranchised by Referendum A. They want a multi-faceted, comprehensive solution to state water supply problems, not just large-scale storage. Referendum A did not give them that choice. Furthermore, the voting process itself further polarized constituents, and moved everyone further away from a rational solution with mutual benefits.

Walter Lippman, writing in his 1920's classic *Public Opinion*, says that people form opinions based not on education but on long-held beliefs and values. But if we believe the public *can* be educated, where do we expect them to receive education about complex issues such as water supply? The media does not educate; it gives us sound bites based on the deeply held beliefs and values of those trying to promote their side of an issue. People hear what they want to hear, based on their own deeply held beliefs and values. What can be done to break down those deeply rutted paths? Would collaborative vs. adversarial approaches pull people together—re-engage them, open them up to new ways of looking at issues?

Some say our adversarial system of power politics supports endless conflict among competing interest groups and leaves little room for open-ended exploration of mutually beneficial solutions. Adversarial politics promotes power hoarding and does not allow for the development of trust and respect which can lead to solutions which take into consideration the interests of various stakeholders. As long as solutions for the common good have to compete in an adversarial environment dominated by vested interests, we are fighting an uphill battle.

What Can We Learn about Consensus Building in the Public Policy Arena?

What can we learn from the social sciences to help us solve water supply conflicts? We have a great deal of research into technological solutions. What we most need is to put more of our resources into social technologies—research into ways to bring together divergent viewpoints. We have only begun to understand the inner workings of deliberative models and their social potential. Often we hear that the social sciences, the so called soft sciences, are really the harder sciences to study and to apply. That is surely true, and the challenge is formidable. But it seems that, under the excuse "you can't change human nature" we have failed to take on the challenge. Are we overlooking the potential for truly globe-changing solutions which could be derived from learning how people can come to understand one another and build consensus? We are in great need of experimental laboratories to try out strategies for using conflict creatively and constructively to generate workable and lasting solutions to conflicts.

Consensus Building Models

In *The Tao of Democracy*, Tom Atlee collects and reports on a variety of methods being used to draw on the wisdom of multiple viewpoints to come up with creative, workable solutions for today's complex issues. He claims we need to look at new ways to "do democracy" because elections, polls, and the numerical adding up of our individual opinions doesn't lead to good decisions which build on our collective wisdom. He believes we need to embrace a more comprehensive view of reality: more view points, approaches, and complexity, so that we can get as good a sense of the whole picture as possible. The premise is that conflict can be a powerful generator of quality problem solving. Atlee cites a number of non-adversarial approaches to conflict which are being used by those he calls social process activists.

Citizen deliberative councils are discussed at length. These councils are typically made up of a group of diverse ordinary citizens. Participants are given extensive education on a given issue and assisted in coming to consensus by a trained facilitator. In Denmark, such citizen councils are convened by the Danish Parliament to study an issue, deliberate with the help of a facilitator, and present findings to parliament. The deliberation process calls for weighing the full range of facts, factors, perspectives, options, and consequences related to the issue and often creates new options in the process. Atlee says “Given a supportive structure and resources, diverse ordinary people can work together to reach common ground, creating wise and deliberate policy that reflects the highest public interest.”

U.S. Representative Edward J. Markey speaks of his experience with a citizen deliberative council which undertook an extensive study of telecommunications issues in the Boston area in 1997. Recognizing the political potential of this innovation, he said, “This is a process that I hope will be repeated in other parts of the country and on other issues.” Dick Sclove, from the Loka Institute, was the lead organizer of the effort. Of the experience, he said: “These ordinary citizens ended up knowing more about the subject than the average congressperson who voted on the issue, and their behavior conclusively disproved the assertion that government and business officials are the only ones competent and caring enough to be involved in technological decision-making. This lay panel assimilated a broad array of testimony, which they integrated with their own very diverse life experiences, in order to reach a well-reasoned collective judgment grounded in the real needs of everyday people. To me this example demonstrates that democratizing science and technology decision making is not only advisable, but also possible and practical.”

Stakeholder dialogues are similar to citizen deliberative councils except that the participants are chosen not from the general citizenry, but from groups who hold various, often opposing views on a given issue, and who have a definite “stake” in the outcome. These dialogues have proven especially effective for “issues that have proven immune to conventional legislative solutions.” An emerging form of stakeholder dialogue called The Consensus Council has been championed by former Montana governor Marc Racicot, who created the Montana Consensus Council. In this form of consensus building, a government agency chooses a representative from each significant interest group with a stake in the issue and helps them come to agreement on recommendations, which are then passed in resolution form to the legislature. Politicians back decisions which come out of stakeholder dialogues because they are supportable by a wide variety of constituents. The success of the Montana Consensus Council and that of a comparable one in South Dakota has led to an effort by a major mediation group, Search for Common Ground, to have Congress establish a national Consensus Council. Former U.S. Secretary of Agriculture Dan Glickman is one of those leading the effort. A United States Consensus Council would “serve the nation by promoting consensus-based solutions to important national legislative policy issues, and would convene the stakeholders on a given issue and seek to build win/win agreements—those that reach the highest common denominator among the parties.”

At root, these approaches accept the premise that emotion and intuition have a legitimate place in decision making, and that healthy relationships are a powerful resource for finding solutions. Such an approach addresses the questions, "What are the fears of participants on all sides of the issue? How can we come up with solutions that address those fears?" Truly understanding others with opposing values stems from a chance for meaningful expression of those values, and from this interpersonal understanding can come the motivation to build consensus.

How might we integrate citizen deliberative councils or stakeholder dialogues into our political process such that they could make a significant difference and even become a central feature of our political system? What if meaningful, facilitated dialogue following comprehensive study of issues were to become the norm for our elected officials? Is it too much to ask that in a democracy our elected officials should mirror the diversity in our populations? Can we even imagine a democracy in which elected officials whose views run the gamut come together amicably, study the issues, and make their decisions not in an adversarial way but through facilitated dialogue? Can we imagine true openness to new solutions instead of dogged insistence on pre-formed positions?

The days of water buffaloes brokering deals in smoke-filled rooms is over. We've come far enough to know we have to involve stakeholders and the public in a cooperative process. But are we putting enough into the process to make it work, and are we serious about working the process? If so, why do we keep seeing band-aid bills come out of the legislature and confusing referendums put in front of the voters?

CONCLUSION

This USCID conference is intended to "provide a forum to discuss myriad issues relating to water rights and the appropriation and distribution of water, including applications of technology." One of the issues to be addressed is "who has the right to use the water when available supplies do not meet all the demands?"

This paper proposes that answers to that important question must come from consensus-built public policy. Consensus building as a primary tool must be championed by new visionaries who take the lead to develop and apply soft science technology to bring together stakeholders with conflicting interests. Any consensus building related to water supply problems in Colorado must help folks on multiple sides of the issue understand deeply where various values and beliefs originate, to fully listen to and gain respect for the roots of the view of the other. In exploring those views, creative solutions with potential for acceptance from all can emerge.

ADMINISTRATION OF COLORADO RIVER ALLOCATIONS: THE LAW OF THE RIVER & THE COLORADO RIVER WATER DELIVERY AGREEMENT OF 2003

Jayne Harkins[1]
Robert F. Snow[2]

ABSTRACT

Under federal law developed over the past century, each of the seven Colorado River Basin States of Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming has an allocation to water from the Colorado River. In addition, pursuant to a 1944 Treaty with the Republic of Mexico, the United States agreed to annual deliveries of water to Mexico. This body of law is commonly referred to as "the Law of the River." Under this legal system, the Secretary of the Interior, through the U.S. Bureau of Reclamation, is responsible for the operation of massive storage facilities in the Colorado River Basin. Primary storage in the Colorado River's Lower Basin is provided by Hoover Dam. Within the Lower Basin, California has a "basic" annual allocation of 4,400,000 acre-feet (af), yet has been using significant amounts in excess of this amount since the early 1950s, with recent use exceeding 5,300,000 af. While this use has been legal during this period, continued overuse of the Colorado River by California reduced storage amounts in system reservoirs and threatened the allocations of the other six basin states. This paper will present a case study and an overview of the history, issues, and operation of the Colorado River in the Southwest United States. This paper will have a particular emphasis on the increase in use of water in the Lower Basin and recent developments in the Lower Basin States of California, Arizona and Nevada. This paper will identify legal and operational issues that have been the subject of active negotiations by the Department of the Interior for nearly a decade. This effort, undertaken in close consultation with the seven Colorado River Basin States, lead to a successful agreement in October 2003 on a long-term transfer of Colorado River water from high priority agricultural users in the Imperial Valley to municipal users on the coastal plain in San Diego. The recently executed *Colorado River Water Delivery Agreement* provides a turning point in Colorado River management and operations: it provides the necessary agreement among Colorado River water users in California for an agreed-upon reduction in California's Colorado River use over the upcoming decades. With the successful implementation of this Agreement each state's allocation from the Colorado should be more secure, and these arrangements will demonstrate that there is sufficient flexibility within the Law of the River to meet the changing needs and increased demands for urban use of water in the Colorado River Basin.

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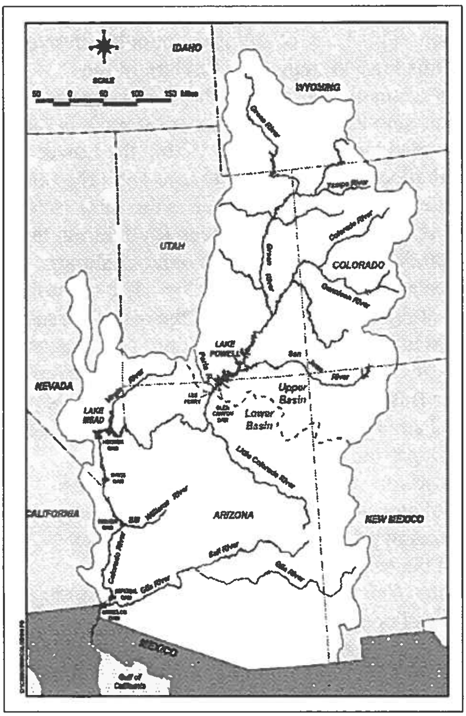
CASE STUDY: THE COLORADO RIVER

Development of the Law of the Colorado River

At the center of the Western United States flows the 1,450 mile-long Colorado River. One-twelfth of the nation's lands, equaling 244,000 square miles, drain to the Colorado. The drainage includes portions of the states of Colorado, New Mexico, Wyoming, Utah, Arizona, California and Nevada (collectively the "Basin States"). The Colorado River forms a portion of the U.S.-Mexico border, divides the states of Baja California and Sonora in Mexico and discharges into the Gulf of California (also known as the Sea of Cortez).



The original name given to the river by the Spanish explorers was the Rio Colorado, which means "Red River" – referring to the red desert sediments that give the river its stunning color.

The Colorado River has been described as the most closely regulated and controlled stream in the United States.[3] Major dams on the Colorado are operated by the U.S. Bureau of Reclamation (Reclamation) in accordance with "The Law of the River"- a broad phrase that attempts to describe a legal framework that includes interstate compacts, the 1944 U.S.-Mexico Water Treaty, federal statutes and regulations, court decrees, water delivery contracts, operating criteria, and other implementing documents relating to the use of the waters of the Colorado.[4]

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[3]Milton N. Nathanson, Updating the Hoover Dam Documents, 1 (Reclamation 1978) (Hoover Update). The Colorado River drains approximately 244,000 square miles, yields approximately 15 million acre-feet (maf) per year and is the lifeblood of the arid southwestern United States. New Courses for the Colorado, at 1 (1986).

[4]2002 Annual Operating Plan for Colorado River System Reservoirs at 1-2 (Reclamation 2002); see also Hoover Update at 1. The use of the shorthand

It is fair to say that controversy and conflict have created the Law of the River, and that the Law of the River also provides the means to manage conflict and facilitate development and use of the River through changing times. It is not possible to discuss the issues regarding use of the Colorado River, however, without a basic understanding and appreciation of the key elements of "The Law of the River."

This paper addresses a central theme that runs throughout the modern history of the Colorado: the concern by the other six states and users in the basin with California's demands on, and use of, the Colorado River. These concerns predated the Colorado River Compact of 1922, and remained unresolved and at the forefront of Colorado River negotiations until Secretary Gale Norton executed the Colorado River Water Delivery Agreement of 2003.

Colorado River Compact of 1922: The relative rights of the Upper and Lower basins of the Colorado were established by the Colorado River Compact of 1922, with each basin receiving a right to 7.5 million acre-feet of water in perpetuity.[5] Congress had authorized negotiation of a "compact"[6] among the Basin States and,

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phrase "the Law of the River" has generated various debates about what is or is not part of the "Law of the River." That debate, while entertaining, is not likely to ever have a definitive answer. The general practice at the Department of the Interior is to reference the phrase "applicable federal law" or to reference particular federal statutes, etc., when describing the legal basis for particular actions and/or decisions.

[5]Colorado River Compact, Article III(a) (1922). The allocation of water to the Upper Basin serves the states of Colorado, New Mexico, Utah, and Wyoming. The waters allocated to the Upper Basin are quantified and administered pursuant to the Upper Colorado River Basin Compact of 1948 and the operation of the state laws of the respective states. Act of April 6, 1949, ch. 48, 63 Stat. 31). Under the provisions of the Upper Basin Compact, the Upper Basin states receive the following specific percentages of the total quantity of consumptive use annually and are apportioned in perpetuity: Colorado (51.75%), New Mexico (11.25%), Utah (23.00%), Wyoming (14%). In addition, a small amount of Upper Basin water (50,000 afy) has been allocated to Arizona pursuant to the Upper Basin Compact, reflecting the small portion of Arizona that lies within the Upper Colorado River Basin drainage. The allocation of water to the Lower Basin serves the states of Arizona, California and Nevada. The Compact also allows the Lower Basin "the right to increase its beneficial consumptive use of [the Colorado River system] by one million acre-feet." Colorado River Compact, Art. III(b) (1922). This right has not been exercised and is not within the scope of issues addressed by this article.

[6]Authority for states to make agreements or "compacts" is contained in Art.I, § 10 of the U.S. Constitution ("No State shall, without the Consent of Congress, ...

in 1922, then Secretary of Commerce Herbert Hoover (who later became the 31st President of the United States) was called upon to facilitate an agreement. The need for the 1922 Colorado River Compact was created by California's early and significant development utilizing the river's water. This use created fear among the other six basin states that California would acquire a superior right to Colorado River water under the doctrine of prior appropriation – as applied on an interstate basis within the Colorado River system.

While the objective of the 1922 Compact negotiations had been to provide a specific allocation of water to each of the seven Colorado River basin states, the negotiators were unable to reach agreement on this point, and had to settle on a perpetual allocation to the Upper and Lower Basins.[7] Having made the allocation between the Basins, the express provisions of the 1922 Compact provide that the Compact would become binding only after approval by the legislatures of each of the seven basin states.[8]

After adoption of the 1922 Compact, disputes between Arizona and California regarding their relative rights to the lower basin's allocation led Arizona to refuse to ratify the Compact. In response, Congress developed an alternate mechanism for ratification of the Compact in the Boulder Canyon Project Act of 1928: ratification by six states, including California, <u>if and only if</u> the California legislature,

> agree irrevocably and unconditionally ... as an express covenant ... that the aggregate annual consumptive use of water of and from the Colorado River for use in the State of California ... shall not exceed four million four hundred thousand acre-feet of the waters apportioned to the lower basin States.[9]

With Arizona refusing to ratify the Compact, and with ratification from Colorado, Nevada, New Mexico, Utah and Wyoming, all that remained for the effectiveness of the Compact was action by California pursuant to this provision of the Boulder Canyon Project Act. The California Limitation Act of 1929 was enacted by California in fulfillment of this requirement and on June 25, 1929 President Hoover (who, as noted above, previously served as the federal representative to

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enter into any Agreement or Compact with another State ..."). This mechanism for interstate agreements predates the U.S. Constitution by over a century.

[7]See fn. 5 supra.

[8]Colorado River Compact, Article XI (1922).

[9]Boulder Canyon Project Act, § 4(a) (1928) (codified at 43 U.S.C. § 617c(a)).

the Compact negotiations) proclaimed that the conditions required for Congressional approval of the Compact had been met.[10]

Boulder Canyon Project Act of 1928: In addition to approval of the 1922 Compact, and authorization for construction of Hoover Dam, the Boulder Canyon Project Act also served to impose an allocation of the Colorado River water within the lower Basin. In the absence of an agreement within the lower Basin, Congress provided its own method for a complete apportionment of the mainstream water among Arizona, California, and Nevada. Arizona v. California, 373 U.S. 546, 595 (1963) (Az.v. Cal. Opinion).[11] This provision of Boulder

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[10]California Limitation Act (Stats. Cal. 1929, ch. 16); Presidential Proclamation (46 Stat. 3000) (1929); Boulder Canyon Project Act at §§ 4(a), 13 (codified at 43 U.S.C. §§ 617c(a), 617*l*).

[11]The Arizona v. California litigation was initiated in 1952 and involved, in part, the quantity of water that each Lower Basin State had a legal right to use out of the waters of the Colorado River and its tributaries. Az. v. Cal. Opinion at 550-51. The case was one of the most complex and extensive in U.S. Supreme Court history: oral argument alone lasted over 24 hours before the Court between 1961 and 1963. Id. at 551. The Court found that the Boulder Canyon Project Act had vested the Secretary with broad authority to administer the waters allocated to the Lower Basin:

> In undertaking this ambitious and expensive project for the welfare of the people of the Lower Basin States and of the Nation, the United States assumed the responsibility for the construction, operation, and supervision of [Hoover] Dam and a great complex of other dams and works. .... All this vast, interlocking machinery--a dozen major works delivering water according to congressionally fixed priorities for home, agricultural, and industrial uses to people spread over thousands of square miles--could function efficiently only under unitary management, able to formulate and supervise a coordinated plan that could take account of the diverse, often conflicting interests of the people and communities of the Lower Basin States. Recognizing this, Congress put the Secretary of the Interior in charge of these works and entrusted h[er] with sufficient power, principally the § 5 contract power, to direct, manage, and coordinate their operation. Subjecting the Secretary to the varying, possibly inconsistent, commands of the different state legislatures could frustrate efficient operation of the project and thwart full realization of the benefits Congress intended this national project to bestow. We are satisfied that the Secretary's power must be construed to permit h[er], within the boundaries set down in the Act, to allocate and distribute the waters of the mainstream of the Colorado River.

Canyon Project Act authorized the Secretary to execute contracts for the Lower Basin's 7.5 maf apportionment as follows: Arizona - 2.8 maf, California - 4.4 maf, and Nevada - 0.3 maf.

After passage of the Boulder Canyon Project Act the Secretary undertook the process of contracting for the lower Basin's apportionment. Within California, representatives of agricultural and urban entities that utilize Colorado River water recommended an approach to the Secretary that was embodied in the "Seven Party Agreement" of August 18, 1931. The quantities and priorities recommended by this agreement are reflected in Secretary's 1931 implementing regulations and water delivery contracts.

California has developed a massive agricultural and urban infrastructure that is dependent on imported Colorado River water, and as shown in Table 1 below, the contracts executed by the Secretary exceed California's apportionment by nine hundred and sixty-two thousand acre-feet.

Since the early 1950s, California has consistently used more than its apportionment of 4.4. million acre-feet, with use in some years exceeding 5.3 maf. California has relied on two legal mechanisms to access water in excess of its 4.4 maf apportionment: unused apportionment and surplus water. Both of these mechanisms are consistent with applicable provisions of the Law of the River, in particular, the Supreme Court's Decree in Arizona v. California.[12]

Arizona v. California, 373 U.S. 546, 588-90 (1963). After issuing its opinion in the case in 1963, the Court issued a Decree in the case serves as a "blueprint" for the Secretary's actions pursuant to the provisions of the Boulder Canyon Project Act and the other elements of applicable federal law. The Decree also imposes a permanent injunction on the Secretary and limits the Secretary's actions with respect to the water master function on the lower Colorado River.

[12]Arizona v. California, 376 U.S. 340 (1964) (Decree) at Art.II(B)(2) ("surplus") and Art. II(B)(6) ("unused apportionment"). Unused apportionment refers to water that is unused in any year by a lower basin state; surplus water refers to water authorized for release by the Secretary for use in the lower basin in excess of 7.5 maf.

Table 1: Priorities and Quantities of California's contracts for Colorado River Water reflected in 1931 regulation promulgated by the Secretary of the Interior

Priority	Description	Annual Amount
1	Palo Verde Irrigation District (104,500 acres)	>3.85 million acre feet (priorities 1, 2, 3(a), 3(b)
2	Yuma Project (Reservation Division) (25,000 acres)	
3(a)	Imperial Irrigation District and Coachella Valley County Water District	
3(b)	Palo Verde Irrigation District (16,000 acres of mesa lands)	
4	Metropolitan Water District	550,000 af
	Sub-total: Priorities 1-4	*4.4 million acre feet*
5(a)	Metropolitan Water District	550,000 af
5(b)	City and/or County of San Diego *(Note: San Diego's contract has been merged with MWD's)*	112,000 af
6(a)	Imperial Irrigation District and Coachella Valley County Water District	>300,000 af (priorities 6(a) and 6(b)
6(b)	Palo Verde Irrigation District (additional 16,000 acres of mesa lands)	
	Total: Priorities 1-6(b)	*5.362 million acre feet*

<u>Role of The Secretary under the Decree in Arizona v. California:</u> The role of the Secretary on the lower Colorado River (generally defined as that part of the river between the upper reaches of Lake Mead and the Mexican border) is unique in the United States. The Secretary serves the function commonly referred to as that of a "water master" and administers delivery of the waters of the mainstream of the

Colorado below Lee Ferry, providing for delivery of water to the Lower Division states of Arizona, California and Nevada, and to the Republic of Mexico.[13]

The Secretary manages the lower Colorado River system in accordance with federal law, including, in particular, the Supreme Court's Decree. The Decree guides the actions of the Secretary in her role as water master and provides that the "United States, its officers, attorneys, agents and employees ... are hereby severally enjoined" from acting in a manner that is inconsistent with the water management provisions embodied in the Decree.[14] The Decree enjoins the Secretary from releasing water stored in Lake Mead except for specific identified purposes: primarily the satisfaction of the allocations to the lower Basin states and the Republic of Mexico.[15]

The system established by the Decree provides for three quantities of water supply: "normal" years when 7.5 maf is available,[16] "shortage" years when less than 7.5 maf is available,[17] and "surplus" years, when more than 7.5 maf is available.[18] The Secretary is authorized by the Decree to determine the conditions upon which such water may be made available; i.e., to determine whether it is a "normal", "surplus," or "shortage" year.[19]

Subsequent to the Court's issuance of the Decree, in the 1968 Colorado River Basin Project Act, Congress required the Secretary develop a set of operating criteria for the coordinated long-range operation (LROC) of the reservoirs on the Colorado.[20] This Act also requires the Secretary, beginning in 1970, to make annual determinations of available water supply in a report describing projected operations for the current year and requires that the report be issued no later than January 1st of each year.[21] This report is routinely referred to as the "Annual

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[13]Mexico is allotted an annual quantity of 1.5 million acre-feet per year (mafy) pursuant to Article 10(a) of the Treaty titled *"The Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty Between the United States of America and Mexico,"* signed February 3, 1944 (1944 U.S.-Mexico Treaty).
[14]Decree at Art. II, 376 U.S. at 341.
[15]Id. The only identified exceptions to releasing water for downstream consumptive use are flood control operations, river regulation, and improvement of navigation. Id. Releases for power are also identified in Art. II of the Decree.
[16]Decree at Art. II(B)(1), 376 U.S. at 342.
[17]Decree at Art. II(B)(3), 376 U.S. at 342.
[18]Decree at Art. II(B)(2), 376 U.S. at 342.
[19]Decree at Art. II(B)(1)-(3), 376 U.S. at 342.
[20]Colorado River Basin Project Act of 1968, § 602(a) (codified at 43 U.S.C. § 1552(a)).
[21]Id. at § 602(b) (codified at 43 U.S.C. § 1552(b)).

Operating Plan" or "AOP" and is the document in which the Secretary determines available water supply for the lower Basin States each year.[22]

Annual Secretarial Determinations in the Lower Basin: California's Use, The AOP Process and the Surplus Determinations under the Long-Range Operating Criteria: Figure 1, below, shows California's annual consumptive use from the Colorado River over the past century, including its use since issuance of the Supreme Court's Decree in Arizona v. California in 1964.

While California has been using water in excess of its basic allocation for decades, up until the 1990s neither Arizona nor Nevada were using the full amounts of their Colorado River apportionments. As noted above, the Decree authorizes the Secretary to release water that is unused by one state in any year to meet the consumptive use needs of authorized users in another state or states.[23]

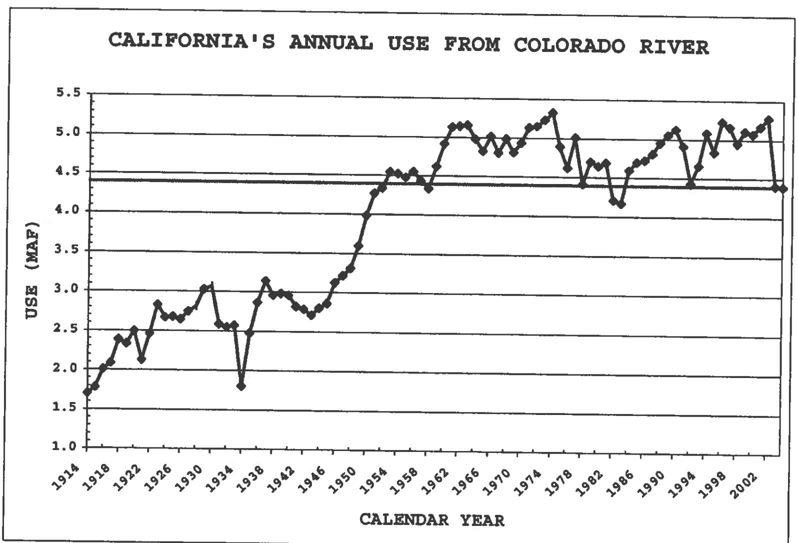

Figure 1: California's Annual Consumptive Use from Colorado River

Under this authority, the Secretary allowed California to utilize unused Arizona and Nevada apportionment. In the early 1990's, however, Arizona and Nevada

[22]The AOP is prepared by Reclamation, acting on behalf of the Secretary, in consultation with representatives of the Colorado River Basin states, academicians, representatives of interested environmental organizations, and other members of the general public, as required by § 602(b) of the Colorado River Basin Project Act of 1968, as amended.
[23]Decree at Art. II(B)(6), 376 U.S. at 343.

began approaching their full entitlements and it became apparent that California would soon have to begin curtailing its use in a "normal" year. The need for California to plan for this transition from use in excess of 5 million acre-feet to its basic apportionment of 4.4 maf has been a focus of intense efforts over the past decade.

The Long-Range Operating Criteria (LROC), discussed above, provide a set of narrative criteria for the Secretary to apply when deciding on available water supply.[24] By considering various factors, including the amount of water in storage and the predicted natural runoff, the Secretary makes an annual determination whether there is sufficient water available in a single year to provide Arizona, California, and Nevada water users more than their basic 7.5 million-acre foot entitlement for consumptive use. If the determination is made that this water is available, the Secretary can make it available to users in these three states as "surplus" water.

With California's demands steady at over 5 maf, high reservoir conditions in the late 1990's allowed the Secretary to declare "surplus" conditions based on the fact that Lake Mead reached near full capacity and was in fact releasing millions of acre-feet of water under flood control conditions. Surplus water was made available to California on this basis during the period 1997 through 2000.

Applying the Law of the River &Adoption of the Interim Surplus Guidelines

In the early 1990's, consumptive use in the Lower Basin began approaching the 7.5 maf Lower Basin allocation (see Figure 2). As a result of increasing demands in the Lower Basin, especially given the increase in urban use, the Upper Basin States became concerned that the Lower Basin would be unable to live within its 7.5 maf compact apportionment.

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[24]The Long-Range Operating Criteria (LROC) were adopted by the Secretary on June 4, 1970 (35 Fed. Reg. 8951) and are subject to review "at least" every five years. See LROC at Introductory Paragraphs. Id.

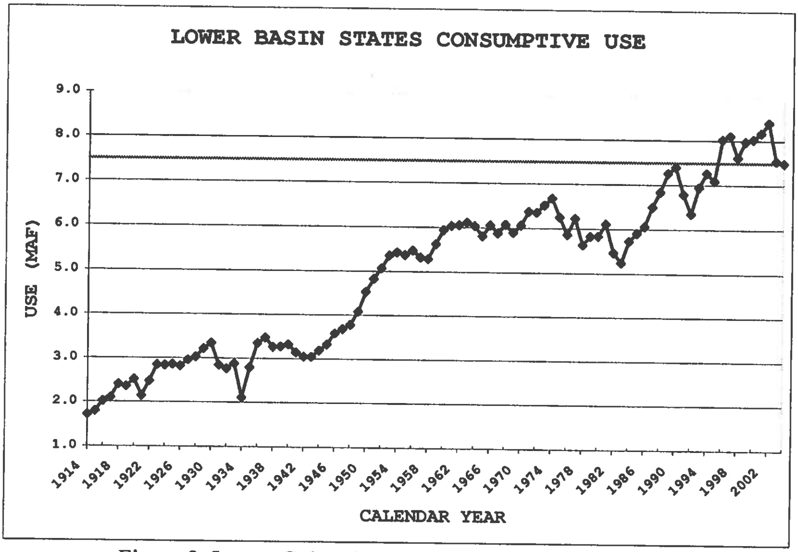

Figure 2: Lower Colorado Basin States Consumptive Use

Intensive discussions among the Basin States took place during much of the 1990s that focused on a need for California to develop a credible plan to live within its basic apportionment of 4.4 maf. There was also a recognition that, even with a detailed "4.4 Plan", California would also need time to implement the plan. This was commonly referred to as a "soft landing" period, a timeframe to allow California to put a variety of programs into place to begin to reduce their use of Colorado River water.

In response to concerns of the other six basin states, California prepared a draft California Colorado River Water Use Plan that described numerous options for California's reduction in Colorado River water use. Reclamation and the Basin States also engaged in studies of Surplus Guidelines, looking at various alternative methodologies of guidelines that could accommodate California's desire to have relaxed conditions for determinations of "surplus" while implementing its "4.4 Plan."

In light of the very general nature of the narrative factors for determinations of surplus identified in the LROC,[25] representatives of the other six Basin States feared that the Secretary would be unable to cease making water available as "surplus" water in light of the steady demand for water in the urban sector of southern California. Imposition of a "normal" year would involve reducing the Colorado River water supply of the Metropolitan Water District (MWD), which

[25]See LROC at Art. III(3)(b).

serves cities between Los Angeles and San Diego by up to 600,000 af or nearly 50% of its imported Colorado River supply. The prospect of such drastic reductions to MWD's Colorado River supply was a motivating factor for all parties to address the need for both a "California 4.4 Plan" and a strategy to allow California a "soft landing."

In 1997, with storage in the reservoir system high, and a large snow pack in the Basin, Reclamation ordered flood control releases from Lake Mead for the first time in a decade. Accordingly "surplus" determinations were made in the Annual Operating Plan based on these high runoff years. In short, the pressure was reduced - somewhat - for a few years to determine how the Lower Basin would live within its normal year apportionment.

In 1998, the San Diego County Water Authority (SDCWA) and the Imperial Irrigation District (IID) developed a plan to transfer conserved water from the agricultural district to the coastal plain for SDCWA. With this plan, issues arose including the verification of reduction in use by IID that would be transferred to SDCWA (and potentially MWD). The need to quantify the Colorado River allocations of some or all of the California agencies with contracts with the Secretary would be crucial to the verification of conserved water and the success of this transfer. At a minimum, quantification of IID and CVWD was needed in order to allow orderly transfers among the California water entities.

The California parties worked together and in 1999 adopted the "Key Terms Agreement" that identified the quantification of IID and the CVWD, as well as transfers of conserved water from IID to SDCWA.

While high reservoir conditions in the late 1990's were allowing surplus determinations to be made on a "flood control" basis, the six Basin states were very concerned that surplus determinations would also be made at lower reservoir and inflow conditions, thereby reducing system storage and placing the other users in the basin at risk.

In particular, lower reservoir elevations place Arizona at an increased risk of shortages. Despite Arizona's victory in the Supreme Court in the Arizona v. California litigation, California was still able to extract a final concession from Arizona. In exchange for California's support of Congressional authorization for the Central Arizona Project (CAP), Arizona agreed to allow its CAP water to have a subservient priority to that of California during times of shortage on the Colorado River system.[26]

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[26]See Colorado River Basin Project Act of 1968 at § 301(b). This was a significant concession since CAP water use represents more than half -- approximately 1.5 maf of its 2.8 maf - of Arizona's apportionment, and serves the municipal and irrigation sectors between Phoenix and Tucson, Arizona.

The states pressed the Secretary to develop objective criteria that would be used in these annual water supply determinations. The Secretary agreed that more specific criteria would aid in the annual decisions made in the AOP process and formally initiated work to develop and adopt surplus guidelines on May 18, 1999.[27]

The Secretary of the Interior adopted a Record of Decision incorporating final Interim Surplus Guidelines (Guidelines) on January 18, 2001.[28] The guidelines that were ultimately adopted by the Secretary in the ROD were based upon a consensus proposal crafted by the seven Colorado River Basin states and submitted as a recommended approach in mid-2000.[29] As adopted, the Guidelines supplement the more general factors provided in the LROC and are to be applied by the Secretary in the development of the AOP for the 15 year period beginning in the 2002 AOP and through preparation of the 2016 AOP.[30]

The Guidelines are based on a "tiered" or "stairstep" approach to surplus determinations, linking the elevation of Lake Mead operations to the availability of surplus water within the Lower Basin (see Figure 3 below). The Guidelines provide "surplus" water to the Lower Basin even under conditions at which Lake Mead is roughly 90 feet below its full elevation.[31]

Thus, the Guidelines are much more permissive with respect to declaring surplus availability than had been the Secretary's prior administrative practice.[32] As noted

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[27]See 64 Fed. Reg. 27008 (May 18, 1999).
[28]Record of Decision, at § 4(a), Final EIS, Colorado River Interim Surplus Guidelines, 66 Fed. Reg. 7781 (Jan. 25, 2001). These guidelines are labeled as "interim" as they were only adopted for a 15 year period.
[29]As a technical matter, the Seven Basin States Alternative was submitted to the Secretary as a "comment" from the seven states during the comment period on the Draft Environmental Impact Statement. *See* 65 Fed. Reg. 48531 (Aug. 8, 2000). Subsequently this alternative was identified as the preferred alternative in the Final EIS and selected, with minor modifications, in the Secretary's Record of Decision. *See* 66 Fed. Reg. 7772 (Jan. 25, 2001).
[30]Interim Surplus Guidelines, § 3, 66 Fed. Reg. 7781 (Jan. 25, 2001).
[31]Id. at § 2(A)(1), 66 Fed. Reg. 7780.
[32]In addition to years in which flood flows were required to be released from Lake Mead, the Secretary had made surplus water available considering the relevant factors listed in the Long Range Operating Criteria, as well as considering several other approaches. One of the approaches is referred to as the "70R" approach that is based on nearly a century of recorded streamflow data. The "70R" analysis involves assuming a 70th-percentile inflow into the system, subtracting out the consumptive uses and system losses and checking the results to see if all the water could be stored or if flood control releases would be required. If flood control releases would be required, additional water is made available as "surplus" water.

above, the Interim Surplus Guidelines were adopted for a limited period of 15 years, through year 2016. The ISG did not guarantee surplus over the 15 years, and surplus water is only provided *if* the hydrology warranted the availability of additional water.[33]

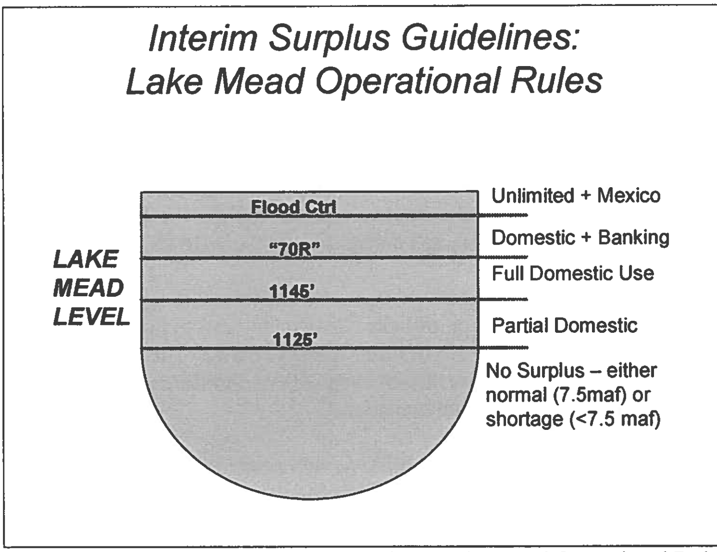

Figure 3: Interim Surplus Guidelines: Lake Mead Operational Rules

Attempts to Adopt a California "4.4 Plan"

Requiring reductions in use by California: The Interim Surplus Guidelines & The QSA: The more permissive surplus determinations incorporated in the Interim Surplus Guidelines, were conditioned on California taking certain actions to reduce its reliance on surplus water. This would allow California to be in a

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The notation "70R" refers to the specific inflow where 70 percent of the historical runoff is less than this value (17.4 maf) for the Colorado River basin at Lee Ferry. 2001 Annual Operating Plan for Colorado River Reservoirs at 19 (Reclamation 2001). The Surplus Guidelines adopt an alternative approach for a fifteen year period and base surplus availability to Lake Mead elevations which are well below the levels which produce flood control releases under the 70R analysis.

[33] See Record of Decision, Interim Surplus Guidelines at "Implementing the Decision, § 4, Relationship with Existing Law: These Guidelines are not intended to, and do not: a. Guarantee or assure any water user a firm supply for any specified period." Interim Surplus Guidelines, Record of Decision, 66 Fed. Reg. 7772 (Jan. 25, 2001).

position to live within its 4.4 maf allocation by 2016 (the end of the 15-year "interim" period).

In this way the Surplus Guidelines adopted a "Trust but Verify" approach to California's promised reductions in Colorado River water use. In order to assure that California actually takes the necessary actions to reduce its use of Colorado River supplies, the Guidelines include certain "benchmark" clauses that required California to take specific actions over the 15-year period of the Interim Surplus Guidelines.[34] Failure to meet the identified benchmarks would lead to suspension of the permissive provisions of the Surplus Guidelines (and revert to the 70R analysis for surplus determinations).

The first benchmark, completion of the California Quantification Settlement Agreement (QSA) was the subject of significant controversy in 2003.

The stated purpose of the "benchmark" provisions was to provide an incentive to California to implement its plan to reduce its use of Colorado River water. A critical element in California's plan was execution of the Quantification Settlement Agreement (QSA), an agreement among Imperial Irrigation District, Coachella Valley Water District (CVWD), and the MWD. The QSA provides a mechanism for "quantification" of California's unquantified priorities within 3(a) (see Table 1, *supra*).

The QSA also contemplates and facilitates a transfer of conserved water from the Imperial Irrigation District to San Diego County Water Authority pursuant to a 1998 Agreement between IID and SDCWA. This agriculture to urban water transfer, on a willing buyer/willing seller basis, allows urban areas to underwrite the cost of conservation efforts to free up additional water supplies. These transactions are implemented through an agreement with the Secretary that will allow a change in place of use for water that was anticipated to be conserved by IID.[35] The period of the transfer is up to 75 years.

When the four California agencies failed to complete the QSA, the result was – as required by the Guidelines - suspension of the more permissive bases for surplus determinations in calendar year 2003. Application of the much more restrictive criteria previously utilized by the Secretary led to declaration of a "normal" or 7.5 maf supply for 2003.[36]

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[34]Interim Surplus Guidelines, § 5, 66 Fed. Reg. 7782 (Jan. 25, 2001).
[35]The issues raised by the transfer include impacts on the Salton Sea as a result of water conservation activities by the Imperial Irrigation District. Various issues are involved in the proposed transfers, including the potential to utilize fallowing rather than on-farm conservation. These issues are beyond the scope of this paper.
[36]Interim Surplus Guidelines, § 5, 66 Fed. Reg. 7782 (Jan. 25, 2001).

Continued Efforts to Adopt QSA

As noted above, the Interim Surplus Guidelines expected that the California Colorado River contractors would execute the Quantification Settlement Agreement, and its related documents, among the IID, CVWD, MWD and SDCWA by December 31, 2001. The Guidelines also provide, as noted above, that in the event that the California contractors and the Secretary had not executed these agreements by December 31, 2002, the interim surplus determinations for Full and Partial Domestic surpluses would be suspended. The surplus determinations would then be based upon a very conservative strategy for the remainder of the 15 years of the ISG or until such time as California completed all required actions and complied with reductions in agricultural water use as specified by the ISG.

In a number of contexts the Department of the Interior made clear that it would enforce the benchmark deadlines in the Interim Surplus Guidelines.[37] The California parties were unable to reach agreement on the provisions of the QSA by the Guidelines' deadline of December 31, 2002, and as a result, the 2003 AOP required that Lower Basin deliveries be limited to 7.5 maf in 2003, with California, Arizona and Nevada limited to 4.4 maf, 2.8 maf, and 0.3 maf, respectively.

Enforcing the Law of the River and the First Phase of Litigation

In light of the inability of the four water agencies to reach agreement on the Quantification Settlement Agreement by Dec. 31st, the Secretary of the Interior imposed the 4.4 million acre-feet legal limit on California beginning Jan. 1, 2003.

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[37]See. e.g., Federal Register Notice Regarding Implementation of the Interim Surplus Guidelines, 67 Fed. Reg. 41733 (June 19, 2002). See also, Formal Remarks of Secretary Norton to the Colorado River Water Users Association, December 16, 2002 :

> I signed the 2003 Annual Operating Plan this morning. The Annual Operating Plan implements the Surplus Guidelines. It provides that if the California entities do not sign the QSA, surplus deliveries of water to Southern California cities will automatically be suspended in 2003.
>
> ...
>
> If the California entities choose not to take the steps necessary for the gradual, voluntary reductions contemplated under the seven-state agreement, California will lose access to extra water available under the Interim Surplus Guidelines. In such an event, California will be forced to live within its 4.4 million acre-feet apportionment from the Colorado River in 2003.

Formal Remarks of Secretary Norton, at 3 (Dec. 16, 2002).

This action reduced California's allocation during calendar year 2003 by approximately 800,000 acre- feet (i.e., from 5.2 maf to 4.4 maf).

The Imperial Irrigation District (IID), which received a reduction of approx. 231,000 acre-feet, sued the U.S. on January 10, 2003, alleging that the method the Secretary used to reduce California to its 4.4 maf limit violated the District's water rights under federal and state law. The other entity that was reduced in January 2003 was the Metropolitan Water District (serving the greater Los Angeles metropolitan area), which lost 40% of its requested 2003 supply from the Colorado River.

IID's complaint also raised claims based on violation of the separation-of-powers doctrine, violation of IID's water rights, along with alleged violations of the National Environmental Policy Act, the Endangered Species Act, and the Administrative Procedures Act.

Subsequently, on January 27, 2003, IID filed a motion for a Preliminary Injunction to prevent any reductions in water delivery to IID as a result of the missed deadline. After a hearing, the U.S. District Court granted IID's motion for a preliminary injunction and ordered the United States to conduct a through review pursuant to Reclamation's regulations published at 43 C.F.R. Part 417 as to whether IID's use of water was in compliance with the legal and contractual limits: that is, Reclamation was to "*meticulously* follow Part 417's prescribed procedures in determining IID's reasonable beneficial use [of Colorado River water]..." *Imperial Irrigation District v. United States,* Case No. 03-CV-0069 (W (JFS) (April 17, 2003) (emphasis in original).

During the summer of 2003, Reclamation proceeded to review IID's water use in a public process pursuant to 43 C.F.R. Pt. 417, pursuant to the District Court's order.[38] Reclamation's findings indicated that IID did not require as much water for its reasonable and beneficial use as it had ordered. IID disputed these findings, and submitted voluminous material challenging Reclamation's conclusions. Much attention focused on this "beneficial use" inquiry, as it was the most detailed beneficial use inquiry ever conducted on the lower Colorado River and had the potential to shift significant quantities of water "down" the priority chain by operation of law and contract (water unused by a senior user automatically becomes available for those next in priority). Absent an agreement among the California parties, many predicted that the California water use controversy was on the brink of descending into years of divisive litigation.

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[38]This process is detailed in a Federal Register Notice published at 68 Fed. Reg. 22738 (Apr. 29, 2003).

Colorado River Water Delivery Agreement of 2003

After much legal wrangling, months of negotiations, and significant national attention, the Quantification Settlement Agreement – revised and restyled as the Colorado River Water Delivery Agreement of 2003 – was signed on October 10, 2003.

As the IID to San Diego transfer – the key transfer incorporated in the QSA - proves, the Law of the River has sufficient flexibility to accommodate the transfer of water between agricultural and urban areas in the Lower Basin.[39] This historic new chapter of the Law of the River allows California to honor the solemn promise it made in 1929 to live within an annual basic allocation of 4.4 million acre-feet. The single most important aspect of this Ten-Page agreement is that both the Imperial Irrigation District and the Coachella Valley Water District voluntarily adopted a "quantification" of their Colorado River allocations. This long-term agreement - for up to 75 years - achieves a quantification of these districts and settles disputes dating back nearly 75 years to the early 1930s. With this quantification in place, orderly, market-based transfers of Colorado River water between California's agricultural users and its growing population on the coastal plain are possible.

Figure 4 shows both recent water use within California and the anticipated water use under the QSA in coming decades.

[39]There is great concern as to how the Lower Basin will meet the ever-rising demand for water to serve urban uses within the Lower Basin, particularly in Los Angles, San Diego, Las Vegas, Phoenix and Tucson. The fact that there is approximately 5 million acre-feet (about 65 percent) of water in Lower Basin agriculture provides an ample resource to structure a market on a willing buyer, willing seller basis, that will allow the needs of the Lower Basin to be met within the Lower Basin's allocation.

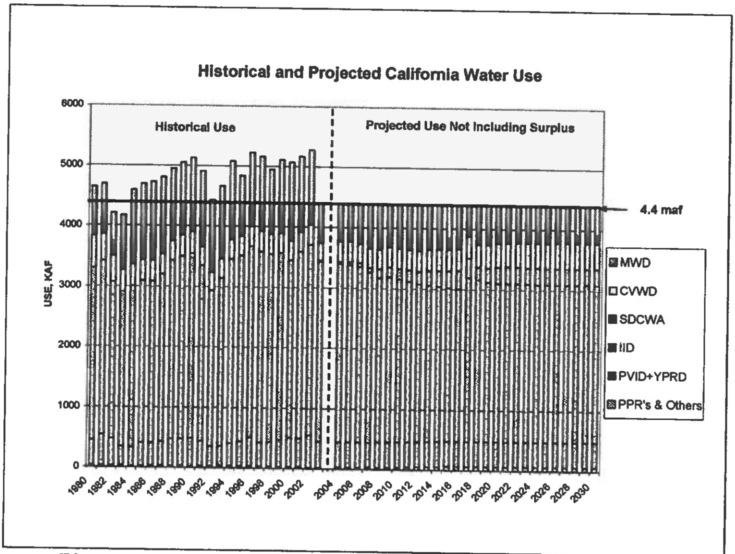

Figure 4: California Water Use 1980-2003 & 2004-2030 (Under QSA)

Current Operations under the Interim Surplus Guidelines (Spring 2004): The New Challenge of the Drought

After reinstatement of all provisions of the Guidelines when the Quantification Settlement Agreement was signed on October 10, 2003, water elevations at Lake Mead provided "full domestic surplus" flows in 2002 and 2003. With prolonged drought and a rapidly declining Lake Mead elevation, a "partial domestic surplus" controlled Lower Basin operations in 2004. Drought conditions have been present in the basin since 1999. Figure 5 below, shows the decline in Lake Mead elevation due to the ongoing drought. As this paper is written, it is unknown whether any surplus water will be available to the Lower Basin in 2005. Current model projections, on which annual surplus determinations are based, indicate that access to surplus water may be suspended as early as January 1, 2005. Even if Lake Mead remains above the "surplus line" for 2005, it is almost certain that deliveries in 2006 will be limited to "normal year" conditions; i.e., releases will be limited to 7.5 maf in the Lower Basin. Moreover, as shown in Figure 6, below, there is a high likelihood that the Lower Basin will not enjoy the benefits of "surplus" water for some time to come.

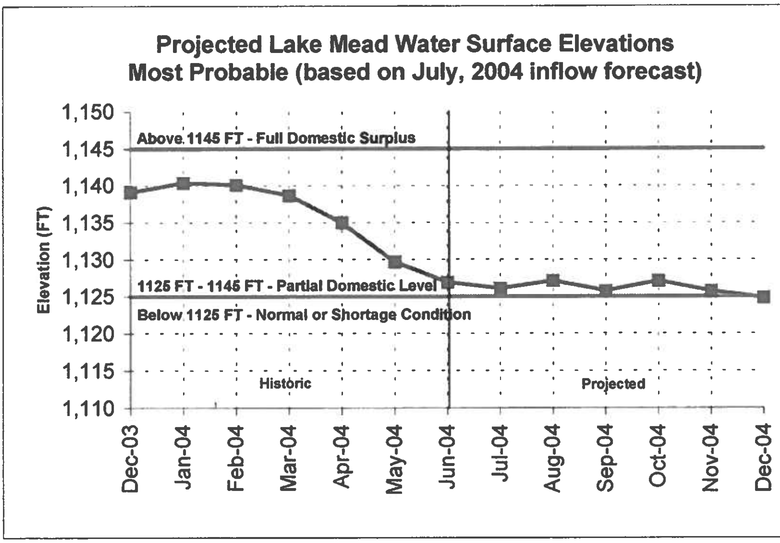

Figure 5: Lake Mead Elevation 1999-2004

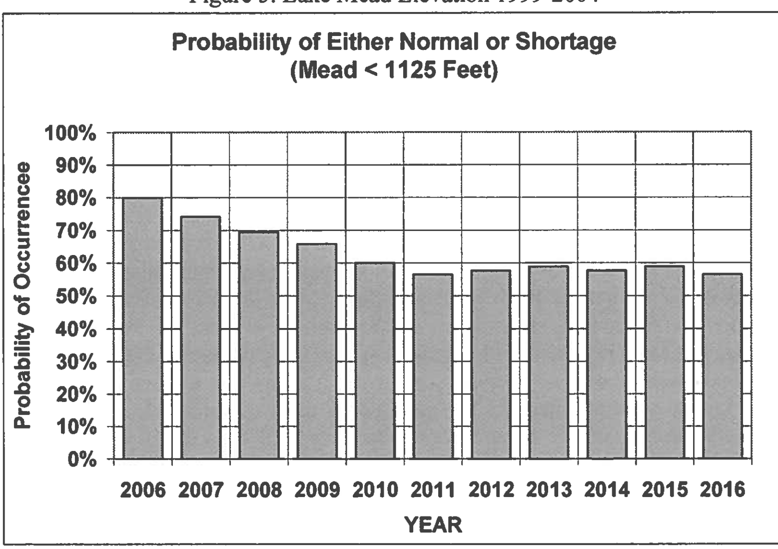

Figure 6: Probability of "Normal" or "Shortage" elevations (<1125') at Lake Mead (based on Interim Surplus Guidelines) 2006-2016

Next Steps: Addressing the Drought

Flows in the Colorado have been abnormally low since 1999. In water year 2000, inflow to Lake Powell was 62 percent of average; in WY 2001, it was 59 percent of average; in WY 2002, it was only 25 percent of average, the lowest on record; and in WY 2003, it was 53 percent of average.

This is the fifth consecutive dry year in the Basin. Since record-keeping began 100 years ago, there have never been six consecutive years of below average runoff (as measured at Lees Ferry).

The month of March 2004 brought the drought into sharp reality. Basin snow pack on March 1, 2004 was 96% of average. Extremely warm and dry conditions over the month of March caused basin snow pack to drop over 30 percentage points. As of July 6th, with this paper going to print, unregulated inflow to Lake Powell this water year is expected to be only 44 percent of average.

In any case, with system capacity in the Colorado River dropping to approximately 50%, the next chapter of the Law of the River is likely to address new forms of interstate cooperation and shortage avoidance strategies.

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PROTECTION OF INSTREAM USES OF WATER UNDER UTAH LAW

Alan Matheson, Jr.[1]

ABSTRACT

Burgeoning population growth in Utah and throughout the West has put increasing pressure on limited water supplies. The resulting competition over a resource necessary for life and livelihood has created growing conflict among water users, with serious consequences. Stream resources are particularly in peril. Healthy streams provide significant economic, environmental and quality-of-life values that are largely unrecognized. Utah has done little historically to protect stream flows. As our scientific understanding increases and society's values embrace sustainable resource development, there is growing momentum for legislation that will enhance protection for natural flows while respecting existing water rights and accounting for future consumptive needs.

INTRODUCTION

Autumn's first reach touched the September afternoon on Boulder Mountain in Southern Utah. The sun ignited gold-spangled aspen groves. The breeze carried a faint bite, portending the season's change. My cousin Mark and I set up camp in a clearing near the headwaters of a small creek. From this humble alpine birth, the creek would cascade to the desert below, join with the Escalante as sculptor of fanciful canyons, and add its voice to the thunderous choir of the Colorado River. The pristine stream was clean, clear and cold, an unspoiled condition increasingly rare outside the world of memory or imagination.

Taking advantage of the lingering daylight, Mark and I rigged our fly rods and headed upstream in search of one of the few remnant populations of native Colorado River cutthroat trout. Our caddis flies danced over shimmering riffles and enticed rising fish in transparent pools. Many of these wild trout likely had never seen an artificial fly, and they readily yielded to temptation. We admired their brilliant coloring and vivid markings, and then gently released them to the current where they flashed to cover. Only the discouraging thought of navigating the return to our campsite in darkness finally pulled us from the water.

Night was dark and clear. From our perch at 8000 feet, the starry display was stunning and humbling—conditions that inspired introspection. Mark and I discussed the legacy we would leave our children. In particular, we wondered whether our children and grandchildren would have the opportunity, as we had, to

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pursue indigenous trout in unsullied, free-flowing waters. The answer to this question lies with us.

THE COST OF APATHY

The concerns underlying the question raised on Boulder Mountain are real. Utah is the second driest state in the nation. Unfortunately, it also ranks second in per capita use of public water supplies. By 2020, Utah will have a million new residents. The consequences are predictable. Certainly, supplies are stretched, putting pressure on water providers to satisfy growing need with expensive new development. In addition, acrimony among water users is increasing. While spirited debate over matters of public policy is healthy, the personalized, vituperative attacks that characterize western water wars lead only to impasse and the further fracturing of our society. Such conditions only increase the challenge of achieving reasonable balance in water management. A third consequence is degradation of natural stream systems. We don't need to look far for an example.

Once a treasured fishery, East Canyon Creek in Summit County, Utah is in serious decline. In August, 2003, the creek dried up—the casualty of unchecked growth in the Snyderville Basin, state-issued water rights that exceed available water supply, development that inhibits groundwater recharge and drought. Where Kokanee salmon used to spawn, trout carcasses lay beached. When the stream does flow, it is often choked with algae and fails to meet state water quality standards for phosphorus and dissolved oxygen.

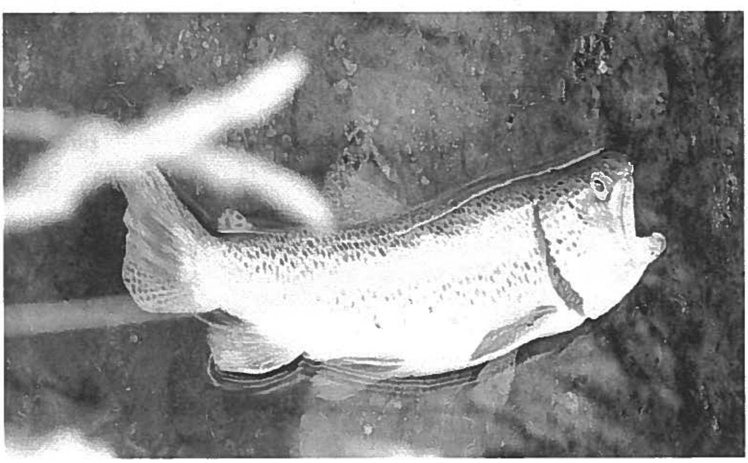

Photo 1: Stranded trout in East Canyon Creek. Photo by Mary Perry (2003).

The degradation of East Canyon Creek comes at significant cost. When the creek slows to a trickle, water treatment costs rise dramatically, real estate values in the area can drop, anglers lose an important fishery, the water quality in the stream and a downstream reservoir becomes worse, and the quality of life that drew many people to Summit County suffers. This is not an isolated situation.

Over 15 years ago, the Utah Division of Wildlife Resources determined that 53 percent of the state's 6,200 miles of stream fisheries "suffer moderate to total losses of fishery potential annually by dewatering. Of the affected miles of stream, more than half lose from 60 percent to 100 percent of their natural flow by diversion."[2] The trend since then is not favorable and is not limited to Utah.

A water budget presented by the U.S. Forest Service in 1989 calculated average annual net streamflows for the nation's water resource regions and then deducted estimated needs for instream flows. The analysis showed that "instream flows in the Rio Grande, Upper Colorado, and Lower Colorado water resource regions are insufficient to meet current needs for wildlife and fish habitat, much less allow any additional offstream use."[3]

THE VALUE OF NATURAL STREAM FLOWS

Western water law generally recognizes hosing leaves off driveways, operating decorative fountains, flooding marginal soils to sustain uneconomical pasture, and over-watering non-native grass in our yards as "beneficial" uses of water. If these inefficient uses are beneficial, certainly instream uses should be considered beneficial and given reasonable protection.

Nearly a century ago, one of our nation's greatest jurists, Justice Oliver Wendell Holmes, writing for the Supreme Court, said:

> [F]ew public interests are more obvious, indisputable and independent of particular theory than the interest of the public of a State to maintain the rivers that are wholly within it substantially undiminished, except by such drafts upon them as the guardian of the public welfare may permit for the purpose of turning them to a more perfect use. This public interest is omnipresent wherever there is a State, and grows more pressing as population grows. It is fundamental, and we are of the opinion that the

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[2] Mark A. Holden, "The Importance of Instream Flow and Recreational Needs in State Water Planning," paper presented at the Sixteenth Annual Conference, Utah Section, American Water Resources Association, Salt Lake City, Utah, April 21, 1988.

[3] Guildin, R.W., *An Analysis of the Water Situation in the United States: 1989-2040.* U.S. Forest Service General Technical Report RM-177 (1989).

> private property of riparian proprietors cannot be supposed to have deeper roots.
>
> . . . The private right to appropriate is subject not only to the rights of lower owners but to the initial limitation that it may not substantially diminish one of the great foundations of public welfare and health."[4]

This statement by one of the day's staunchest defenders of private property rights is prescient of the modern water debate and reflects an understanding that the worth of water is not expressed only outside of the stream bank. As the Supreme Court implicitly recognized, non-consumptive uses of water have economic, environmental, and quality-of-life values.

Economic Value

Recently, the National Research Council and many distinguished economists have concluded that resources such as water have "nonuse" (or "nonconsumptive use") values and that these values are as real as traditional commodity production values.[5] A year ago, more than 100 economists from across the nation sent a letter to President Bush and the governors of western states telling them that protecting and enhancing the West's natural environments would strengthen the ability of western communities to generate more jobs and higher incomes. "The West's natural environment is, arguably, its greatest, long-run economic strength," the economists wrote. "Nearly all communities of the West will find they cannot have a healthy economy without a healthy environment."

Support for this conclusion is found in a 1990 study that compared the marginal value of water left in streams to enhance downstream fisheries with the marginal value of water withdrawn for irrigation. The study, conducted by the U.S. Department of Agriculture, reviewed all 99 major river basins of the contiguous United States and concluded that the marginal value of water for recreational fisheries exceeds its marginal value for irrigation in 52 of the 67 watersheds in which irrigation occurs.[6]

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[4] *Hudson County Water Co. v. McCarter*, 209 U.S. 349 (1908).

[5] National Research Council, *A New Era for Irrigation.* Committee on the Future of Irrigation in the Face of Competing Demands. Washington: National Academy Press; National Research Council, *Watershed Research in the U.S. Geological Survey.* Committee on U.S. Geological Survey Water Resources Research. Washington: National Academy Press (1997); National Oceanic and Atmospheric Administration. Natural resource damage assessments; proposed rule, 60 Fed. Reg. 39804-39834 (1995).

[6] Hansen, LeRoy T., and Arne Hallam, "Water Allocation Tradeoffs: Irrigation and Recreation," Resources and Technology Division, Economic Research

Similarly, George William Sherk—a research professor in the Department of Engineering Management and Systems Engineering at George Washington University and practicing attorney—recently surveyed several studies that addressed the economic benefits that have been or could be derived from the protection of instream flows. Based on this survey, Sherk concluded:

1) The results from the studies "strongly suggest that protection of instream flows has the potential to produce significant economic benefits."

2) "[T]hough cost determinations are always location-specific, the costs of providing water to fulfill instream flow requirements are relatively insignificant given the benefits produced. For example, restoration of the Trinity River in 1998 would have produced annual benefits of $406 million at a cost of between $17 and $42 million. Use of federal reservoir water in 1987 to provide flows in the Rio Chama would have provided benefits ranging between $868 and $1,040 per acre foot. Instead, this water was sold by the federal government for $40.00 per acre foot."

3) "[A] failure to protect instream flows could have devastating impacts on any rural economy dependent on water-oriented recreation and tourism. Two studies addressing this question concluded that willingness to pay declined between 80% and 93% when adequate streamflows were not provided. A third study concluded that willingness to pay 'declined significantly' when streamflows were inadequate but did not quantify the extent of the decline. One study also concluded that water-based recreation was a key element in diversifying and developing rural economies."[7]

Fishing is an important element in the economic value of stream flows. The U.S. Fish & Wildlife Service found that more than half a million anglers age 16 and older fished in Utah in 2001, contributing nearly $400 million in retail sales and nearly $1 billion in total output to the state's economy. These anglers supported nearly 10,000 jobs and accounted for over $37 million in state taxes. The economic contribution of fishing in other western states is even greater.[8] While not all fishing expenditures are associated with streams, one need only visit the Provo and Green Rivers in Utah, or the blue ribbon rivers in surrounding states, to know that flowing water generates vibrant economic activity.

Service, U.S. Department of Agriculture, Agricultural Economic Report Number 634 (June 1990).

[7] Sherk, G.W., White Paper entitled "Protecting Instream Flows: An Economic Benefits Summary" (2002).

[8] U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, U.S. Census Bureau. *2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.*

The water quality benefits of healthy flows also have an economic component. Cleaner stream flows translate into reduced treatment costs. In addition, they mitigate the stunningly expensive corrosive effects of salts and other elements on water-delivery infrastructure.[9]

Environmental Value

The environmental value of stream flows should be self-evident. Leonardo da Vinci said, "Water is the driver of Nature," and so it is. Decades of habitat alteration have led to the extinction or near-extinction of many aquatic species. Fully 35 percent of listed species are aquatic. More than 20 native western fishes have become extinct in the past century, and 100 more are considered threatened, endangered, or of special concern, including Utah's state fish, the Bonneville cutthroat trout. Loss of all these species would mean destruction of 70 percent of all fish species native to the lands west of the Rocky Mountains.[10] The wildlife benefits of healthy stream habitat are not limited to aquatic species. In fact, 80% of wildlife in Utah spends at least a portion of its life cycle in riparian areas.

Healthy flowing streams provide crucial environmental services, all of which profit man and nature. Natural flows recharge groundwater—a critical function in many parts of the West where water tables are declining. Healthy streams produce cleaner water, which reduces treatment costs and improves public health. For example, in the summer of 2002, the Utah Division of Water Quality issued advisories warning the public not to wade in certain popular streams because low flows caused them to violate health-based water quality standards. In addition, flowing streams provide other critical services such as sediment and nutrient transport and channel, temperature, floodplain and habitat maintenance.

Quality-of-Life Value

Rivers provide other benefits that are, perhaps, less tangible, but no less real. Henry David Thoreau said: "Who hears the rippling of rivers will not utterly despair of anything. We go to the river's edge for comfort, spiritual renewal, meditation, solitude; we go to the river to feel and know the continuance of life." Indeed, some of my life's best moments are associated with rivers: a childhood walk along the Logan River with my father; skipping rocks in the Snake River with my brothers during a family vacation; jumping from a cliff into Tonto Creek with my wife-to-be to celebrate our engagement; and finding insight and

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[9] Reisner, M. and Bates, S., Overtapped Oasis: Reform or Revolution for Western Water (1990) at 58-59.

[10] Minckley, W.L., Sustainability of Western Native Fish Resources. In W.L. Minckley (Ed.), *Aquatic Ecosystems Symposium*. Denver, CO: Western Water Policy Review Advisory Commission. Springfield, VA: National Technical Information Service (1997).

inspiration on a quiet riverbank as I contemplated serious questions in life. No doubt most people have memories of rivers that are equally cherished. Too often trivialized, these moments of replenishment are essential to our physical, emotional and even spiritual health in a loud, rushed, uncompromising world. Flowing water is the music of renewal.

In discussing the value of instream flows, I am not suggesting that all flows should be protected or that all withdrawals should stop. Certainly, our economy and very lives depend on a clean, adequate water supply for domestic, industrial, and agricultural uses. We need reasonable water development. In addition, we must also recognize the interests of existing water rights holders who legitimately have obtained valid and valuable rights under prevailing law. Both these interests and stream systems can be respected and enhanced if we make the most efficient and effective use of the resource.

EFFORTS TO PROTECT UTAH'S STREAM FLOWS

Obstacles to Stream Protection

If we accept that flowing streams have value, we should protect that value under law. Nevertheless, progress toward balanced streamflow protection in Utah has been slow. Several factors create resistance to instream flow legislation. One factor is the persistence of outdated attitudes about water. Surprisingly, there are some people who still believe, despite overwhelming evidence to the contrary, that any water left in a stream is wasted.

A second impediment is the unfortunate use of the environment as a political football. Only in recent years has the environment become a divisive political issue, largely based on a false "economy vs. environment" dichotomy. All of our major environmental laws passed with broad bipartisan support. The vast majority of us believe that we should exercise wise stewardship over the earth, making reasonable use of its resources to meet our legitimate needs, while ensuring the availability of those resources and the proper functioning of natural systems into the future. Nevertheless, prevailing political rhetoric does not reflect this common belief. In our charged political climate, anyone advocating riparian health is labeled by some as a "radical environmentalist" or falsely accused of not caring about people. Under these social conditions it is difficult to pursue even balanced resource policies. We must get out of the political trenches when it comes to lakes, rivers and streams. There is no greater commonality among mankind than our relationship to water. As Theodore Roosevelt said: "Our duty to the whole, including the unborn generations, bids us restrain an unprincipled present-day minority from wasting the heritage of these unborn generations. The movement for the conservation of wild life and the larger movement for the conservation of all our natural resources are essentially democratic in spirit, purpose, and method."

A third factor is the legitimate concern of some water users and planners that we not implement an instream flow program that harms existing rights or limits our ability to meet future water needs. These concerns are understandable, but they can be addressed adequately—and have been in several states. While Utah should proceed purposefully with an enhanced instream flow law, the process should be open and the review comprehensive so we don't create unintended consequences.

Legislative Activity

The concept of stream protection has its roots in early Utah history. The pioneer settlers entered the Salt Lake valley on July 24, 1847. On July 25th, some of the men began to construct a dam on City Creek. Brigham Young saw what they were doing and bade them stop, saying, "Brethren, don't war against nature!"[11] Of course, in order to survive in a harsh desert climate, the settlers needed to divert water for irrigation, but as Brigham Young directed, they didn't fully stop the flow of the creek. Brigham Young's charge was perhaps the first act of stream flow protection in the territory. It was many years before the Utah Legislature took tentative steps to recognize the value of stream flows.

Utah's first statutory instream flow law passed on February 12, 1986 and strictly limited the ability to create instream flow rights. Only the Division of Wildlife Resources could hold an instream flow right. The right could only be created for the preservation or propagation of fish. Unappropriated water could not be appropriated for purposes of instream flows. And the Division of Wildlife Resources could not obtain a water right for instream flow purposes without legislative approval.[12] As a practical matter, streams remained unprotected.

The instream flow statute has been amended twice. In 1987, the Legislature made insignificant stylistic changes. In 1992, a coalition of water interests that had wrestled for months over ways to make the statute more effective, presented their recommendations to the Legislature. In response, the Legislature made modest amendments to broaden the opportunity to acquire instream flows. The Division of Parks and Recreation obtained authority to hold instream flow rights and the purposes for which an instream flow could be acquired were expanded to include public recreation and preservation or enhancement of the natural stream environment. In addition, the requirement of prior legislative approval was eliminated, although State Parks and Wildlife Resources still could not purchase a

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[11] Paul Cox (Director, National Tropical Botanical Garden), keynote address presented at a conference entitled "Our Stewardship: Perspectives on Nature," Brigham Young University, February 27, 2004.

[12] Smith, J.C., *Little More than a Trickle . . . Utah's Instream Flow Law.* American Water Resources Association Conference, "Water Conservation in the 21st Century: Conservation, Demand, and Supply" (1995).

water right for instream flows unless the Legislature specifically appropriated funds for that purpose. The statute remains in this form today.[13]

The Legislature designed Utah's instream flow statute to be weak, and the statute works exactly as designed. In its eighteen years of existence, the statute has been used to create only four small instream flow rights, all held by the Division of Wildlife Resources, and all received by donation. Utah lags far behind her neighbors in the West in protecting natural stream flows.

Speaking on water resource management in November 2000, Nelson Mandela said: "It is one thing to find fault with an existing system. It is another thing altogether, a more difficult task, to replace it with another approach that is better." Taking Mandela's observation to heart, a broad coalition of interests organized nearly four years ago to explore opportunities to make Utah's instream flow statute more effective. Several fundamental principles guided the discussions. First, creation of instream flow rights must not harm existing water right holders. Second, a limited market approach could create opportunities to benefit both streams and water right holders. Third, participation in instream flow transactions should be voluntary. And fourth, water right holders should have more flexibility to use their water right as they wish, consistent with the rights of others.

The coalition drafted a bill that reflected these principles. In short, it would allow political subdivisions of the state and qualified nonprofit organizations, in addition to the designated state agencies, to hold rights to water instream. Instream flows could not be created through condemnation and no instream flow transaction could be approved if it would harm existing water rights. This bill would allow, for example, water right holders who are not using their full allotment to lease a portion of their water rights to an organization that would leave the water in the stream. Water right holders would benefit from supplemental income and avoiding forfeiture of their rights. People who use and make a living from rivers would benefit from enhanced flows. Of course, fish and wildlife would also be more secure.

The coalition has met with virtually all water interests in the state to solicit feedback and suggested amendments. The ensuing dialogue has been cordial and constructive. Certainly, there are legitimate concerns that need to be addressed and all parties must assess the impact of the proposal on their interests and identify unintended problems. To this point, however, few have said publicly that the State should do nothing more to protect streamflows, and most water users have said they would support instream flow legislation if existing consumptive rights are respected. During 2003, an interim committee of the Legislature held a hearing on the bill. During the 2004 regular session, the Legislature unanimously passed a bill creating a Water Issues Task Force that will spend the next two years

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[13] Id.

studying complex water issues. Instream flow protection is on their agenda. This is a sound approach that will allow the issue to be considered carefully to ensure that any resulting bill provides meaningful protection for our most valuable streams without harming existing water right holders or preventing reasonable development in the future. The Task Force will be successful if it stays above the political fray, draws on input from all of Utah's varied water interests, and puts the long-term needs of the State ahead of short-term parochial concerns.

CONCLUSION

I opened this paper describing a trip on Boulder Mountain, and I'd like to return there now. After our night in camp, Mark and I spent the next day working with employees of the Utah Division of Wildlife Resources on a project to expand a fragile population of Colorado River cutthroat trout. Tired, but rewarded, we began our drive home at dusk. The road along the western slope of Boulder Mountain afforded us a spectacular view of a fiery sunset over the Tushar Mountains. We pulled over and watched quietly as the flaming brilliance cooled to glowing embers, then to fading pastels. It was September 10, 2001. The peace of the moment belied the horror that would meet the sun's rise the next morning.

The sobering events of the following day remind us that we can't take what we have for granted, whether resources or relationships. John Sawhill has said, "In the end, our society will be defined not only by what we create but by what we refuse to destroy." It is within our capacity to divert all rivers for other uses and to further fracture our society. It is equally within our capacity to save a measure of our treasured streams and heal the current divide among diverse western neighbors. Doing so will require decisive action beginning today.

In the words of Thomas Moore: "We let a river shower its banks with a spirit that invades the people living there, and we protect that river, knowing that without its blessings the people have no source of soul."

CONVERTING AGRICULTURE WATER TO URBAN WATER SUPPLIES

Tage I. Flint[1]
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ABSTRACT

Northern Utah, along with the vast majority of Utah's population, is located in a unique geographic area generally classified as a mountain desert region. Water is relatively scarce and is the most valuable natural resource. Pioneers who settled this area in the mid nineteenth century put most available water to use irrigating valley lands to grow crops needed for food and survival. As the population center increases, Northern Utah continues to experience a shift to urbanization and the ground that once grew those crops and pastured livestock are now supporting homes, landscapes, and commerce.

Municipal water suppliers have developed the local and relatively low cost culinary water sources and have allocated them to existing urban uses. Those supplies are quickly becoming fully utilized.

Historical water sources used for agriculture in Utah are generally water rights represented by stock in mutual irrigation companies. That stock may not stay with the lands on which it has resided in the past. Water from that stock may be sold and in some cases moved completely out of the region. Conversion of that irrigation water to municipal use on the same lands represents real cost advantages to the municipal supplies. Minus additional development costs, capital expenses are reduced to construction of treatment and distribution.

Water thirsty communities have been paying premium dollars to buy water rights or irrigation company water shares which can be transferred out of original places of use to bolster supplies at the detriment of communities which were historically irrigated with that water. What avenues are available to municipal water providers to keep water in their service areas? What happens if substantial quantities of irrigation water shares leave their service areas? This paper will explore these and other related issues experienced by Weber Basin Water Conservancy District and its customer agencies in Northern Utah. The analysis looks at tried and new conversion programs and planning issues along with

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discussion of marketable water commodities driving future water development and use.

INTRODUCTION

Weber Basin Water Conservancy District

The Weber Basin Water Conservancy District (Weber Basin) is a regional water supply agency which develops and supplies both urban and agriculture water to its customer agencies and lands within its boundaries. Weber Basin's existing water supplies are likely to be inadequate to meet water demands for farms, ranches, cities, recreation and the environment over the next 25 years. A high likelihood for potential conflict exists in the area. Included within Weber Basin boundaries are Weber, Davis, Morgan, Summit and part of Box Elder Counties.

These areas are experiencing explosive growth rates. Utah, as a whole, grew nearly 30 percent in the last decade. Some urban areas are growing at double digit annual percentage rates.

Utah, being the second driest state in the nation, faces unique challenges with inadequate existing water supplies compounded with high growth rates in arid areas and prolonged drought.

Early History of Northern Utah Water Development. Water development began with Euro-American settlements during the pioneer days of the 1840s. On the very day of their arrival in the Salt Lake Valley, July 24, 1847, crops were planted and City Creek was turned out of its banks to irrigate the dry barren soil and thus began the first irrigation recorded in northern Utah. Weeks later construction of a small dam commenced so as to bring water to needed locations in their settlements. Pioneer leaders encouraged them to "construct cooperative canals, open individual ditches and apply water to the land that native fruits and cereals might be produced in sufficient quantities to supply the demand for home consumption." These cooperative efforts that built the canals, developed into water groups. Later Utah law was codified in the form of the Utah Irrigation Act of 1865. This act provided for the development of water districts within counties through the action of mass meetings.

Utah, along with seventeen other western states, adopted the doctrine of prior appropriation. In a region where water was scarce and needed for irrigation, the doctrine of prior appropriation worked better than the common law Riparian doctrine that worked well in the eastern portion of the United States where water was plentiful. The doctrine of prior appropriation stipulates the first claimants in time had the right to the water to irrigate their crops without returning the water to the main stream and did not recognize any right of water in a property owner simply because of property ownership.

In 1880, an act was passed by the Utah legislature that separated water rights from the land. This act coincided with the completion of the Transcontinental Railroad through Utah and a liberal movement to push Utah's economy into the American mainstream. A private property owner could now make water personal property and separate it from the land to transfer it for sale. Later new laws were passed which addressed the acquisition of water rights and created the office of the state engineer to oversee the water rights program.

<u>Management of the Weber River.</u> The Federal Weber Basin Project was planned in 1950 to conserve and utilize for multiple purposes practically all of the presently unused flows of the streams in the natural drainage basin of the Weber River, including the basin of the Ogden River, its principal tributary. The sponsor and operator of the project is Weber Basin. Major project features include 7 dams and reservoirs, 3 diversion dams, about 67 miles of conveyance works including a tunnel, aqueducts, and canal; 3 power plants, 3 drinking water treatment plants, 16 pumping plants and 18 deep wells (see figure 1). Water resources of the area were extensively developed prior to initiation of the Weber Basin Project.

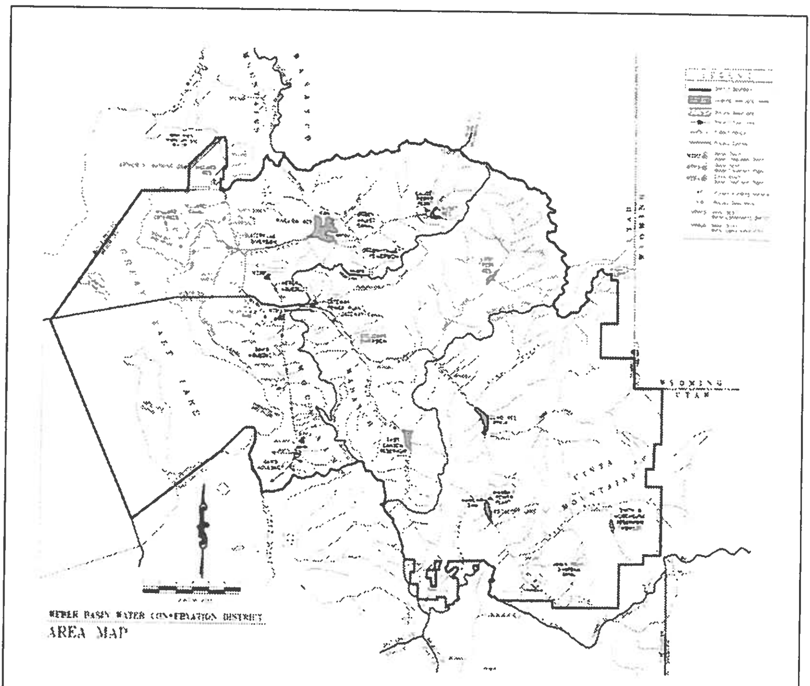

Figure 1. Weber Basin Water Conservancy District Map

Prior Federal reclamation developments included the Weber River Project with its Echo Reservoir on the Weber River. The Ogden River Project with its Pineview Reservoir and conveyance facilities on the Ogden River. Also under the Weber River Project and the Provo River Project, water is diverted from the high reaches of the Weber River to the Provo River for multiple uses in Provo and Salt Lake Counties.

Numerous private developments antedate the Federal projects. The Weber Basin Project supplements all of the earlier undertakings and its operations are correlated with them in approaching full practicable development of the area's water resources.

Beginning on the northwestern slopes of the High Unitah Mountain Range, four river systems have their source near this point. The Weber, the Bear and the Provo all drain to the Great Salt Lake (GSL), while the Duchesne is part of the Colorado River drainage.

The Weber River travels 135 river miles from Scout Lake on Bald Mountain dropping 6,300 feet along its path to GSL. The Ogden River travels about 30 river miles from Causey Reservoir to GSL dropping about 1,400 feet. The Weber River has an average annual yield of 1,091,000 acre feet of Water.

From a distribution standpoint, the Weber River is divided into thirds. The upper district is the part above Echo Reservoir, which includes Chalk Creek, Beaver Creek, Silver Creek, and East Canyon Creek above the Morgan County line, and other small tributaries. Located mainly in Summit County, the upper district is responsible for 26 percent of irrigated acres. Also the Weber Provo Canal crosses the Kamas Valley diverting application water during high runoff, winter power water and Echo reservoir water by exchange to the Provo River.

The Central District covers the area between Echo Reservoir and Gateway, including Echo Creek, Lost Creek, Cottonwood Creek, East Canyon Creek in Morgan County and other small tributaries. According to the Weber River decree of water rights, the Central District diverts only 13 percent of the water rights for irrigation.

The Lower District is bounded on the east by the Wasatch Mountains and on the west by the Great Salt Lake. The Lower District embraces the largest irrigated area utilizing 61 percent of irrigation water rights.

<u>Population, Projections and Water Use Trends.</u> Since the settlement of early pioneers, Weber Basin has experienced a steady growth rate. Population will continue to increase in this area based on quality of life and a number of related factors. Projections indicate the growth rate within Weber Basin will out pace most of the nation. The Government Office of Planning and Budget projects

227,000 new people or a 50 percent increase expected by year 2020 and 467,000 new people or almost a doubling by the year 2050.

Competition between different uses of water will shape the way water resources are used in the future. Agriculture use is currently the primary use of developed water in the Weber Basin. Other uses include Municipal and Industrial (M&I), environmental including Fish and Wildlife, Secondary, Domestic, Replacement and Recreational uses. Sustaining the anticipated population increase will require additional supplies of M&I water. This water may be made available through, transfers, development projects and other water management strategies.

Water Transfers. Converting agriculture water to urban supplies is a process where existing developed water supplies are used with the appropriate State and Federal approvals; to address the future M&I needs of the basin. Agriculture conversions or water transfers typically occur when water rights are either sold or leased or occur when land and water is converted to a different use. Because of the rapid pace of urbanization of irrigated farmland, water transfer represents a significant source of water to meet future M&I demands.

In the mid 1980s, Weber Basin petitioned the United States Department of the Interior Bureau of Reclamation (Reclamation) to convert or transfer from the originally authorized irrigation use up to 33,000 acre feet of water stored in or controlled by Willard Reservoir to M&I use. This transfer was approved in 1989 allowing Weber Basin more flexibility to meet future urban demands.

Reclamation has been, and continues to be, supportive of voluntary transfers and conversions of project water from existing to new users and/or uses. According to Reclamation's manual on voluntary transfers of project water, their overall objective is to "facilitate voluntary transfers of project water between willing parties in a timely and economical manner pursuant to State and Federal law and in such a way that the Federal government is in no lesser financial position than it would have been had a transfer not occurred". Reclamation's policy further indicates that in such situations that are deemed appropriate; Reclamation will, but without compulsion, unless so required by legislative or judicial decision; encourage participants to effect voluntary transfers of project water.

Typically, project water transfers are carefully evaluated as to the potential impacts resulting from the transfer. Private water rights can be transferred without evaluating potential impacts. Pressure to develop in one end of the basin often times promotes competition for water fights and facilitates water transfers to developing areas. Motivation of land owners to sale or otherwise allow these transfers is often based on financial incentives provided by land developers. Basin areas from where transferred water originated are left with a dilemma. Property, which once had sufficient water to properly convert from an agriculture use to urban use, now is left dry. Urbanization of these dry lands places a new demand on the municipality and Weber Basin.

The lower Weber Basin region contains the major population centers of Weber Basin. For years many of the cities have made hookups to the local secondary water provider a condition of development. Some secondary companies have allowed an option of paying a fee for water to the secondary company or provide to the secondary company, the agricultural water stock currently on the property. In the case where shares are provided to the secondary company, 100 percent of the water represented by the shares is then used to provide secondary pressurized water to the residential lawns and gardens, leaving the municipality burdened to acquire water for indoor potable use. Often times the potable demand is placed on Weber Basin for new water development. This transfer process is inefficient. Weber Basin believes that the volume of water required to irrigate agriculture lands is in most cases sufficient to provide for the nonpotable outdoor needs as well as the indoor potable needs of residential communities. On the other hand when secondary companies allow fees to be paid in lieu of turning over water shares, the company assumes a risk that the dollars received are sufficient to purchase the stock required for the development. What we have observed over the years is that market prices of water stock is unpredictable and can fluctuate substantially putting at risk the financial stability of these often times small secondary water providers. When stock purchases are not made, then the water delivery obligation is in default or as often the case other share holders are shorted their rightful volumes of water to satisfy the new demands. Another danger in not purchasing the shares, aside from the misrepresentation problem, is the probability that the money will be used to fulfill other needed obligations such as maintenance or capital improvement activities. If the secondary company is successful and stock is located and purchased by the company, then the same problem occurs and 100 percent of that stock is obligated towards outside nonpotable uses, leaving the municipality or Weber Basin to provided the potable component of the water demand.

<u>Efficient model for a agriculture water transfer.</u> Weber Basin is working with several of its municipal customer agencies on an efficient agriculture water transfer model. By ordinance and as condition for development, agricultural lands are required to transfer their water shares to the City. The City retains ownership of a portion of the water and through pre negotiated contracts with the secondary company, leases to the secondary company the outside nonpotable water needs of the proposed development. Typically this volume represents two-thirds of the full agriculture volume. The balance of the water is transferred to Weber Basin and through contract is treated and delivered back to the city for the potable inside demands of the development.

Benefits of this model are that it puts agricultural landowners and prospective land developers on notice of the water requirements precedent to urbanization or development. As a result the transfer of water rights or shares to other locations has greatly diminished. It also makes efficient use of existing water resources reducing the volume of future water development.

Summary. For many years agriculture use within the basin has declined while M&I uses have increased. While agriculture use is still the biggest use and will continue its dominance at the number one position for many years to come, efficient models put in place by Weber Basin Water Conservancy District and its municipal customer agencies are providing an efficient water transfer mechanism to assist agriculture lands as they undergo urbanization. Lands that are dry for whatever reason will still require the development of new additional water resources.

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"CONSERVED WATER" — IS THERE SUCH AN ANIMAL AND WILL WE KNOW IT IF WE SEE IT?

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Brian Wahlin[1]

ABSTRACT

Water conservation has become a major focus for water users throughout the United States. The focus on water conservation at the local level can and does have impacts well beyond the limits of the local area. This paper explores impacts and issues that can be created by simple conservation of water on the local level. Several examples are given to show how conservation on one project may adversely impact water use by others.

INTRODUCTION

Water conservation has become a major emphasis for water users throughout the United States and the world as water supplies have become more and more limited in the arid regions of the United States. Even the historically water rich eastern portion of the United States has become embroiled in conflicts over water. "Conservation" has become not only a buzzword but a requirement for having adequate supplies to meet increasing demands. As a result more and more cities, water districts and others entities have explored ways to "conserve" their water. Unfortunately, what is sometimes presented as "conservation" is not true conservation when examined from a broader viewpoint.

Today's water supplies are extremely complex and inter-related. The change in quantity of use in one area of a water supply or river system can and does have unexpected impacts to other portions of the water system or to other water users in a river system. The concept of "conserved" water is being discussed in this conference but simply conserving water in one project or area may not lead to an overall water savings when viewed from a river basin perspective. In fact "conserved" water may not be "conserved" at all; it may be simply be reserved for later use by the "conserving" party. "Conservation" may simply mean leaving water in the reservoir for later use by the upstream users at the expense of downstream users that depend on the return flows from the upstream users. Thus the "conserved" water may become unavailable for subsequent use by a downstream water user simply because it was "conserved" by the upstream user. In this paper, upstream user refers to both surface and groundwater users. Thus, the upstream user may not even be on the same stream as the downstream user.

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This complexity adds significantly in the analysis of water use and proposed conservation measures.

This paper explores some of the unintended results of conservation at locations that may be far from area where conservation is being applied.

WATER RIGHTS AND CONSERVATION IN RIVER SYSTEMS

Water uses and water rights have evolved over the last 150 years in most of the western United States and longer in the eastern United States and in parts of the world. Historically the differences in approach to water law among the various areas have been so different that few commonalities could be found. The realization that water is not unlimited, even in the eastern states, has spurred conservation efforts throughout the nation. Existing water rights in both areas are often based on the reuse of water several times on its way to the ocean or ultimate fate (e.g. the Great Salt Lake or the Salton Sea). Environmental and habitat needs overlay another layer of complexity on the use and conservation of water. Water rights and the associated determination of who is entitled to what water are obviously complex and overlay additional layers of complexity and the potential for litigation on water conservation.

Sample Basin

If we first look at a simple system with a reservoir, three downstream surface water users and a groundwater user we can get an idea of what happens when "conservation" is applied on a user by user basis. A diagram is shown in Figure 1 to illustrate this example and aid in the understanding of the various users and locations.

We start by assuming that all of the surface water users have an irrigation system with an irrigation efficiency of 40%. In this case irrigation efficiency is defined as the amount of water beneficially used by the crop divided by the total diversion. Forty percent of the total diversion is returned to the source stream and 20% is lost to groundwater through over irrigation and/or canal and ditch seepage. In this example we also assume that the irrigation diversion takes all of the water from the stream and no base flow is present downstream. If we also assume that water rights are in priority according to use in the river, i.e. user 1 nearest the reservoir has highest priority and user 3 at the tail of the system has lowest priority, we can see the impacts of unbridled water "conservation".

In this example user 1 diverts 100,000 acre feet of water to which they have first priority. Of this total 40,000 acre feet is actually used by crops being grown in the area, 40,000 acre feet is "lost" as return flows and 20,000 acre feet are lost to seepage and over irrigation. User 1's "waste" of water returns to the system and is subsequently used by user 2 according to their water right (40,000 acre feet).

Since user 2 has the same efficiency as user 1, 16,000 acre feet are used by crops, 16,000 ac-ft returned to the river and 8,000 ac-ft "lost" to groundwater. User 3 then uses the 16,000 returned to the river by user 2 with the same results – 6,400 acre feet used by crops, 6,400 returned to the stream either for additional downstream users or, in as in this case, for delivery to the final sink (think Great Salt Lake, Salton Sea, ocean, etc). User 3 also loses 3,200 ac-ft to groundwater.

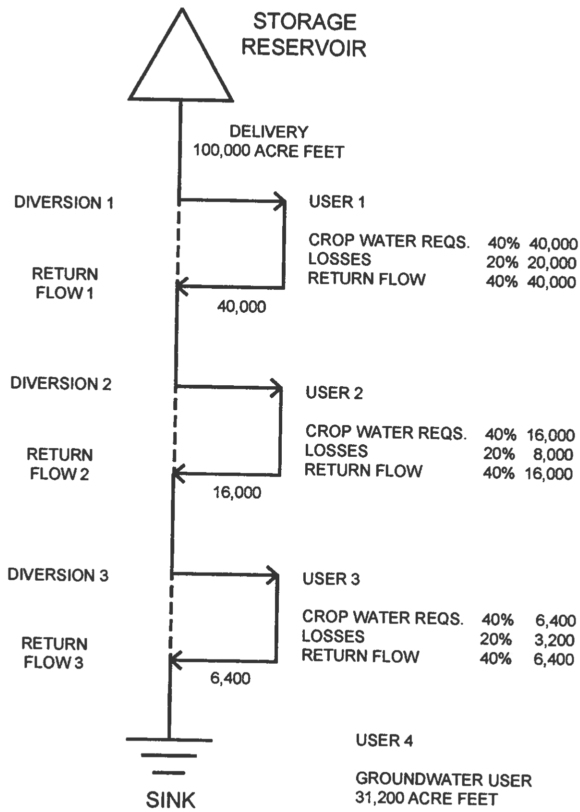

Figure 1. Simple Basin Showing Diversions, Losses and Return Flows.

The total "losses" to groundwater are 31,200 acre feet from the surface users. If we assume that this amount is either returned to the system through springs or used by user 4 we gain a more complete picture of the system. If we assume for this example that user 4 uses the entire 31,200 acre feet for irrigation with an 80%

irrigation efficiency (sprinkler irrigation for example) only about 6,240 acre feet are lost – part to evaporation (3,120) and part to groundwater (3,120). This scenario then accounts for approximately 97% of the total water supply in the basin.

IMPACTS OF CONSERVATION AND CONSERVATION EXAMPLES

Example 1. Upstream priority of use

This example assumes that water rights have priority in line with basin position for our sample basin shown in Figure1. Thus user 1 has the highest priority and user 3 has the lowest surface priority and the groundwater user has the lowest priority.

Having described the basin and water use let's look at the impacts of "conservation". If user 1 "conserves" water by lining canals, switching to sprinkler irrigation and maybe even some drip irrigation systems. As a result of all these changes their efficiency of use increases to 80%. Now let's look at the impact on the system.

User 1 now only needs to divert 50,000 acre feet unless he expands his acreage which we assumed was not allowable under state law. Conveyance losses have been reduced as has return flow. There may be some operational spills due to the timing of releases from reservoirs or the inability of farmers to utilize water when available. Seepage losses will be reduced by linings and the 20% "lost" to inefficiencies may be split equally between surface and groundwater "losses". Under this assumption user 2 now receives only 5,000 acre feet in return flows whereas previously she received 40,000 acre feet.

The 5,000 ac-ft user 2 receives is well short of the crop water requirements of 16,000 ac-ft required for her crops. If user 2 now also conserves water to match user 1's conservation effort (since her supply has been drastically reduced) her return flow under the new scenario reduces from 40% of 40,000 ac-ft or 16,000 acre ft to 10 of 5,000 acre feet or 500 acre feet. This again assumes that irrigation inefficiencies are split evenly between surface and groundwater losses. Return flows could be less than 50% of the losses under this scenario.

User 3 now receives 500 acre feet to supply the original crop water requirements of 6,400 acre feet. (See Figure 1.) This obviously is another huge impact.

We also need to look at the impact to the groundwater user. The "losses" to groundwater prior to "conservation" were 31,200 acre feet. Under the "conservation" plan the aquifer only receives 5,000 acre feet from user 1 (50% of losses), 500 acre feet from user 2, and about 50 acre feet from user 3 (assuming he too "conserves" water rather than just going out of business) for a total of 5,550 acre feet or a reduction of 85% in water availability to the groundwater user – another huge impact.

Up to this point we have overlooked a very important fact – what happens to the 50,000 acre feet that user 1 "conserved"? This is the key to whether water is actually conserved or simply transferred from one user to another. If, as in this case, the highest priority water right is closest to the dam, what can the upstream user do with the conserved water? If he can claim ownership of the "conserved" water he can 1) expand irrigated acreage, 2) sell water to outside users (i.e. cities, industrial uses, etc), 3) simply let the water run down the river to meet downstream users demands or 4) use the water to meet required minimum flows in the river. There are a multitude of scenarios that could be considered but if the water is used by user 1 or transferred to a municipality for use outside the basin of origin most of the water has not been truly conserved but simply transferred from one use and water right to another. Most water transfers will try to minimize the downstream impacts of "conservation" however simple conservation for conservations sake may not be conservation but simply another means to transfer ownership of water rights.

In this case we have conserved 50,000 acre feet of water but have reduced water availability by 36,200 acre feet to downstream users. "Conservation" has resulted in the transfer of ownership to 36,200 acre feet from the downstream users to user 1. Whether or not user 1 is entitled to all of this water is a policy and legal question that must be answered by either the legislature or the courts.

Example 2. Downstream Priority of Use

As an alternative we can look to see what happens when the water rights are reversed in the system. Thus if the highest priority is downstream water must be passed down the river to meet the demands of the lower users. In this case we will also assume that all of the users "conserve" water. If all of the users get their water use efficiencies up to 80% (85% for the groundwater user) then the following results occur as shown in Table 1. A higher efficiency is used for the groundwater user since they often have higher efficiencies due to the cost of energy to pump the water.

In this case water must be passed downstream to keep the downstream and groundwater users whole as would happen when the priority dates are stacked from downstream to upstream – (i.e. the downstream water users can make a call on the upstream user to force water releases down the river to meet their demands). Depending on how efficient the river channel is at transporting water, any savings by the upstream user could be lost in conveyance to the downstream users – much to the delight of the groundwater user.

If the groundwater user is the one who makes the call (i.e. has the priority right) the water must either be recharged or delivered to the user by alternative means which would likely require new pumps and distribution facilities. No one said this analysis was for the faint of heart.

In this case no one is detrimentally impacted by conservation. All of the users have had to make significant investments in conservation measures such as canal lining, sprinkler systems or other measures but so that their crop water requirements are not impaired. The basin has an additional 10,160 ac-ft of water available for other or additional uses which is significantly less than the 50,000 ac-ft from the first example. This looks to be real water conservation but the cost per acre foot would likely be extreme. Some reason other than economics would likely justify this conservation effort – perhaps instream flows or an endangered species.

Table 1. Impacts of Conservation on Water Availability for Example 2

User	Diversion - No Conservation	Diversion - Conservation Scenario	Gross Conserved	Pass to Down Stream Users	Pass to GW User	Net Conserved
User 1	100,000	50,000	50,000	40,000	15,000	+5,000
User 2	40,000	20,000	20,000	16,000	6,000	+2,000
User 3	16,000	8,000	8,000	0	4,800	+1,600
Groundwater User*	31,200	29,365	1,835			+1,835
Totals	187,200	100,000	79,560	56,000		10,435
Diversion Efficiency	1.872	1.00				
Basin Efficiency**	87.4%					97.8%

*Groundwater Users (GW User) often have higher efficiencies due to short distances and closed conveyance systems. Assume groundwater user can increase average efficiency from 80% to 85%.
** Basin Efficiency – Beneficial Crop Water Use / Water Supply in Basin = 87,400/100,000 = 87.4% and (87,400+10,437)/100,000=97.8%

Example 3. Municipal Conservation in Las Vegas, NV

Let's now look at a municipal water conservation program. A large portion of municipal water usage in the west is for landscaping and lawns while another large portion is simply used to transport waste to the treatment plants. Conservation obviously impacts the two primary uses differently. Las Vegas, Nevada, for example, is paying residents to remove lawns and replace them with xeriscape or desert landscaping that requires substantially less water. This is being done under the auspices of a conservation program. Let's examine what happens under this program. The water used for lawns and landscaping is primarily evapotranspirated although some is lost to seepage and deep percolation due to over watering. The reduction of use for landscaping has two impacts. First, the total usage is reduced and less is evapotranspirated. Second, since the groundwater down slope from Las Vegas is contaminated, water lost to the groundwater may not be easily recoverable and the groundwater flow tends to pollute water in Lake Mead. This analysis leads to the conclusion that the reduction of lawns and landscaping is truly conservation and water not used for irrigation is "conserved" for other uses in the city. Any water used for these purposes becomes unusable for other purposes and thus is truly "lost" from the local water supply (i.e. it is unavailable for additional uses or users).

The second primary use of municipal water is the transport of waste to the treatment plant. This water is usually released into an existing water body – either a river, stream or lake. In the case of Las Vegas, it is released into Las Vegas Wash which flows into Lake Mead. This water is mixed with lake water and is again available for use either by Las Vegas or by downstream Colorado River users. The "conservation" of this water has large implications in terms of treatment and pumping costs since it is brought from the lake at a much lower level than the city and treated for municipal use and then retreated prior to release back to the wash and lake. Additional implications are present in terms of erosion and headcuts in the Las Vegas wash; however, in terms of water conservation no water is really lost or rendered unrecoverable. The reduction of usage by individual users may make the treated water go further and thus reduce costs but unless the return flow is not credited to the city or not available for downstream users, conservation really has no impact on the overall water availability. This system is basically a recirculation system with a high degree of mixing with reservoir water prior to reuse.

Salt loading of the return flows from the city is also a recognized problem in the Las Vegas Wash. There are ongoing efforts to reduce salt loading as well as other pollutants in the Las Vegas Wash.

Example 4. Big Wood Canal Company, Idaho.

This example is an actual surface irrigation project located in south central Idaho. The project overlays the north edge of the Snake River Plains Aquifer and irrigated acreage totals approximately 36,500 acres. According to the Lynn Harmon (Harmon, 2004), Manager of the canal company, the project needs approximately 270,000 acre feet for a full season (May to September) and has storage for 191,500 acre feet. Based on these numbers and an estimate of crop water requirements at 36 inches per year, the project could "conserve" approximately 60% of its current usage (Mr. Harmon estimates losses in the 50-55% range). This obviously would require large capital investments to eliminate seepage losses, reduce operational losses to a minimum and to otherwise control the water. The canal company is currently contemplating reducing their water losses by lining some sections of their canals but is short on funding sources. The question is "Would their lining efforts conserve water in a regional sense or simply transfer water from one user to another?"

If we look at the area being irrigated we see some interesting features. Excess water that runs off in the upper portions of the project is recaptured and reused lower in the project. It can thus be used to meet the water rights of individual users further down on the Big and Little Wood River systems. Very little water actually escapes from the system except for some minor amounts that drains into sinks and cannot be recaptured. Thus, the water that is diverted for the project, and not lost to seepage, is almost entirely used for crop production.

As stated above the project overlays the northern edge of the Snake River Plains Aquifer which is a huge aquifer covering a swath clear across Southern Idaho. Given the size of the aquifer it may be that the 102,000 acre feet being lost (delivered) to the aquifer by the Big Wood Canal Company may not be significant. However, this year water rights holders with rights to spring flows along the Snake River (the outlet for the aquifer under the Big Wood Canal Company lands) issued a call for water due to low flows from the aquifer. This would have impacted over 1,000 wells in the eastern Snake River Plains Aquifer. Whether the Big Wood Canal Companies 102,000 acre feet is significant enough to be noticed in the aquifer and when it would be noticed is open to question. If the aquifer was smaller – along a river for example the 102,000 acre feet may be enough to cause wells along the river to go dry bringing into conflict the rights of the surface water irrigators and those of the groundwater irrigators.

In this case the Big Wood Canal Company holds rights dating to approximately 1912 while those issuing the call for water have rights from the 1960's to 1970's. Big Wood Canal Company would therefore not be impacted unless their plans to conserve water were challenged on the grounds of historical beneficial use or some other grounds.

Let's assume that Big Wood Canal Company was able to tap into some of the wealth in nearby Sun Valley, Idaho and enclosed their entire system and installed pressurized irrigation systems. What would happen to the "conserved" water in this case? In normal or better water years some of the water that had been "conserved" would be passed down river as spillage from the reservoir during snow melt periods or during winter releases. Inflow to the aquifer would be reduced dramatically since flow would be concentrated in the river channel and not spread across the irrigated area. The spillage would enter the Snake River and be available for use for hydropower, irrigation, water supply or other uses below the boundaries of the aquifer underlying the company lands. Unfortunately most of the storage for irrigation in Idaho is upstream from this point and water would flow into reservoirs on the lower Snake River (defined here as being below Bliss, Idaho).

In years with less than normal precipitation, losses would be lower and more water would be delivered to farmers and available for use by crops and for extending the irrigation season. This portion of the water would be evapotranspirated or "lost" from the system rather than stored as groundwater for use by others as well as an aid in maintaining the flow at what is know as Thousand Springs (the location of the impaired users).

Thus "conserved" water would help a struggling irrigation district at the expense of down gradient lower priority groundwater users (remember example 1?). While the amount of water "conserved" may or may not have significant impacts downstream given the size of the aquifer, the fact that a call has been made would indicate that this conservation would adversely impact lower priority users. A detailed surface and groundwater study would be necessary to view the extent of the impacts of water conservation on the area. Whether or not total water usage would increase or decrease under a conservation plan would need to be analyzed.

Example 5. Upper Colorado River and Saline Groundwater / Return Flows

In the Grand Junction region of western Colorado the soils are highly saline and deep percolation from the farms in the area contribute 580,000 tons of salt to the Colorado River per year (USBR, 2004). In this case the conservation of water means a reduction in the amount of on farm "losses" and a reduction in the amount of highly saline groundwater flowing into the Colorado River. This salt has consequences from the source of the salt near Grand Junction clear to the mouth of the Colorado River in Mexico.

In this instance if water is "conserved" the amount of water available may not change dramatically if we assume the conserved water will continue to flow down the river rather than being diverted and used elsewhere (the eastern slope of Colorado for example). The quality of the water may improve markedly downstream, however, due to the conservation of water on the irrigated lands (read conservation as reduction in application amounts). This reduction in use will actually reduce water requirements downstream by reducing the leaching requirements and salt loading problems. This would equate to conservation since less water is required for downstream crops.

In this example the goal is not really water "conservation" but rather the reduction of salt loading in the Colorado River. This shows that water conservation may not be the goal at all but rather the means to accomplish the ultimate goal. Thus conservation as practiced in the Grand Junction area may not conserve water locally but rather conserve it downstream.

Example 6. The All American Canal and the Mexican Farmers

Currently the All American Canal is unlined and "losing" water to seepage. Recent agreements call for, among other things, the lining of the canal to reduce seepage losses to allow California to get within their limits on Colorado River water usage. Currently the water "lost" to seepage from the canal is pumped by farmers on the nearby Mexican side of the border for irrigation of their crops. The question can again be asked: "Are we really conserving water or simply reallocating to a different use?" It would appear that we are reallocating in this case but a much more detailed analysis would be required than that presented here. This example gets directly into the area of international law and agreements – another analysis not for the faint of heart.

WHAT SHOULD CONSERVATION MEAN?

While the examples given above are very simple they do show potential problems with applying simple analyses to complex problems. Hardly anyone would argue that the conservation of water was not a worthy goal. The maximization of benefits from the use of water is a laudable goal. However; as demonstrated by the previous examples, not every attempt at conservation will actually increase the efficiency of water use in a basin. If changes in the use of water by one entity in a basin are not reviewed in conjunction with the impacts on other users in the basin it is very possible that other users who have made significant investments in terms of capital, time, and effort can be damaged. This could be especially true if conserved water is held to be the property of the conserver with no regard to other users in the basin.

Water conservation should increase water availability in a basin, reduce pollution or provide some other benefit that increases the level of benefits on a basin wide basis rather than to benefit only the one "conserving" the water to the detriment of other users. If no net increase in benefits is obtained or other users are harmed, then reallocation is taking place rather than conservation. The challenge is to identify a way to approach this analysis such that the benefits for the basin from proposed conservation efforts can be evaluated fairly and a basis for sound decisions can be established.

What Does it Mean?

Water conservation is a tremendous goal. The blind application of "conservation" without an understanding of the complex and interconnected nature of the hydrologic system as well as the complex water laws governing its use can lead to unintended consequences. Conservation should not be undertaken without a careful analysis of the goals and consequences of "conservation". The conservation of water may improve the efficiency for the upstream user but may reduce the efficiency of the overall river basin by not making the water available for downstream use.

PROPOSED DEFINITIONS

As a part of developing this paper a few proposed definitions or clarifications to definitions have been developed. They are by no means presented as to be absolute but to be starting points for further discussion necessary to arrive at a way to logically address water conservation questions and to help guide a discussion of how to fairly evaluate water conservation proposals.

Basin Water Losses

Water that becomes unavailable for later reuse in the basin for any reason. The reasons may be due to the impairment of water quality such that it becomes uneconomical to recover the water (for example, salt, polluted aquifers, MTBE, or other problems) or that the water is allowed to flow to a place such that the economics make it physically unrecoverable (very deep groundwater or small amounts in physically remote closed basins. It would also include water that was non-beneficially evaporated or evapotranspirated. It would not, however, include water that is necessary for wildlife or aquatic habitat, minimum flows, or other environmentally sound goals as these would be considered beneficial uses.

Basin Water Efficiency

The efficiency of use in an enclosed area including the uses of surface water and groundwater while accounting for the reuse of water by multiple users. This would allow for the comparison of various "conservation" schemes to see if water is really being transferred or simply reallocated within the basin. A proposed equation would be as follows:

$$\text{Basin Water Efficiency} = \frac{\text{Total Beneficially Used}}{\text{Total Basin Supply}}$$

Basin Surplus Conserved Water

Water that could be available for other uses if the measures being contemplated were implemented. This could be water that would be available for transfer or for expanded use when existing uses are considered and accounted for.

Water Conservation

The saving of water currently lost to evapotranspiration, to low quality surface water or groundwater, or to physically unrecoverable locations as well as the extension of existing uses without impairing environmental qualities or other existing users.

HOW DO WE APPROACH WATER CONSERVATION

One approach would be to treat "conserved" water as being a new water right subject to prior appropriations and priority dates. This, however would limit the incentive to develop conserved water – especially for those holding early water rights. It would however protect other users in the basin. The other extreme is to give all of the conserved water to the one implementing the conservation practices. This policy, as we have shown can have serious consequences downstream. The most likely is a policy that provides incentive to conserve water within the entire basin while protecting downstream and later users that have come to depend on the water previously "lost" due to inefficient use by the upstream user.

CONCLUSIONS

Water conservation is an extremely worthy goal. The problem comes in determining whether the "conserved" water is really conserved or simply reallocated from one use to another. Whether water is actually conserved really depends on whether the water to be conserved is currently lost from the system (i.e. becomes unusable) or whether the water is simply made unavailable to another user. This requires a much broader analysis of conservation than is found in most of the conservation discussions.

The question that we need to ask in evaluating water conservation plans and projects is "Whose water are we conserving?" Once we have the answers to this question we can evaluate whether a water conservation project is real or simply an attempt to unilaterally reallocate existing water rights. Real water conservation should increase the available supply for the highest uses while reducing the amount of water lost to areas where it cannot be economically recovered such as polluted aquifers, non productive salt sinks, etc.

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RIGHTS TO WATER IN THE CONTEXT OF ETHIOPIA'S DEVELOPMENT

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ABSTRACT

At a National level, Ethiopia has relatively abundant water resources, yet the natural temporal and spatial variation, compounded by limited development, means that access to reliable water supply is a major constraint in many parts of the country. An expanding population and efforts to rapidly develop the economy, with water resources as a major component, further increase demand, particularly in drier seasons and periods of drought.

In addition to the well-publicized natural catastrophes that have befallen the country, major political changes, from the Imperial and Derge Regimes to the present Government, have disrupted indigenous arrangements and attempts to formalize water rights. In recent years, with the devolution of authority to the regions, the institutional challenges to rationalizing access to water have further evolved. The situation is further complicated by the fact that many of the major basins in the country are international rivers, with 86% percent of the Nile flow originating within Ethiopia. Although this paper's primary focus is on rights to water at sub-National levels, the international aspect of the resource will be presented.

This paper presents an overview of the issues and constraints associated with access to water in various parts of the country. The history of rights to water in Ethiopia, considering indigenous systems and more recent attempts to regulate water management reviewed with regards to the technical, social, institutional and economic realities. The present situation is discussed, and the needs and practical strategies for the future are explored, particularly within the context of the country's development.

INTRODUCTION

At a National level, Ethiopia has relatively abundant water resources, yet the natural temporal and spatial variation, compounded by limited development, means that access to reliable water supply is a major constraint in many parts of

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the country. An expanding population and efforts to rapidly develop the economy, with water resources as a major component, further increase demand, particularly in drier seasons and periods of drought.

Given this expected increase in demand for water, this paper presents an overview of the history of how water has been regulated in the country, the social, geographic, technical, institutional, and political settings in which this has evolved, and what the future may hold.

Scope & Limitations

This paper considers water management and the rights to water to meet domestic needs, and water for the agricultural sector. The industrial sector in Ethiopia is very small, but growing and no-doubt the water needs will become significant. Furthermore, environmental needs are being given closer scrutiny as the country moves towards further development of its water resources. However, scrutiny of the environmental and industrial sectors is limited to the general discussion.

The primary focus of this document is the right to water and water management within Ethiopia at the individual, community and basin levels. However, it is important to realize that, as mentioned above, the vast majority of Ethiopia's surface waters, although they originate within the boundaries of the country, are transboundary in nature. Most of these river systems are part of the eastern Nile. Although there are earlier agreements related to the use of Nile and its tributaries, by far the most important agreement to date is the 1959 Nile Water Agreement between Egypt and Sudan (United Nations Treat Series, 1963), which requires the two countries to take a common position on developments by upstream riparian countries, which would affect the available resources. The agreement states that Egypt and Sudan have the acquired rights to 48 and 4 billion m^3 per annum respectively, as measured at Aswan.

OVERVIEW

Ethiopia is reported to produce 122 billion cubic meters of renewable surface water resources every year. In addition, although information is limited, groundwater resources are estimated to be around 2.6 billion. This translates into approximately 1,900-m^3 per capita (WSDP, 2002), which makes Ethiopia relatively water abundant. However, except for the Awash basin and the Rift Valley, the other major basins of the country are transboundary and shared with Egypt, Eritrea, Kenya, Somalia and Sudan. The Abbay, or Blue Nile, Tekezze and Baro-Akobo basins, which all rise in Ethiopia; contribute 86 percent of the annual average flow of the Nile that reaches Lake Nasser. In other words, other countries claim much of the resources that are generated in Ethiopia.

The country has a highly varied topography, with large differences in spatial and temporal rainfall. The lowest point in the country is 110-m below sea level in the Afar depression in the North East and the highest point is the nearby peak of Ras Dashen mountain, which is at 4620-m. Between there are high mountains, high plateaus, deep gorges, incised river valleys, and low-lying plains (Adamsu Gebeyehu, 2003). Because of the topography Ethiopia has a wide range of climates, soils and vegetation.

Average annual rainfall ranges from 100-mm in the low-lying areas of the North East, to 2800-mm in the higher areas of the South West. In the southwest, rain falls for most of the year. In the north, the rain season is less than 3 months. Flows in the river coincide with the rainfall, with limited flows between December and March. Except for the major rivers mentioned above, there are few perennial streams below 1000-m (Abate, 1994).

From a National perspective, 90 percent of the water resources occur in four river basins[3] that host no more than 40 percent of the population. About 60 percent of the population live in the higher lands of the east and central river basins and depend on less than 20 percent of the country's water resources (MoWR, 2001).

In addition to, or perhaps because of, the geographical variation within the country, there is considerable heterogeneity in the sociology, which means that community water management and rights systems are generally quite different from one location to the next.

Further complicating the situation in Ethiopia has been major changes in the political setting over the past three decades. In 1974, the *derg* overthrew the imperial regime of Haile Selassie and, with the backing of the Soviet Union, formed a Marxist regime. The *derg* radically reformed the feudal land tenure system through nationalization, villagization and resettlement (Keeley & Scoones, 2000). Following the defeat of the *derg* in 1991 the country has been reorganized into ethnically based regions, and responsibility for land tenure has been devolved to these regions. Despite an ingrained tendency to remain rather hierarchical, authoritarian and centralized (Keeley & Scoones, 2000), decisions relating to water resources management within a given region are now the responsibility of the regional. To fully understand the how water is management requires a good understanding of the regional context.

Recognizing the need for water resources to be managed in the context of a basin and building on the integrated basin plans developed to date, the Ethiopian Government is in the initial stages of developing basin authorities. Presently such an authority has been established for the Abbay (Blue Nile Basin) and for the

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[3] These include the Abay (Blue Nile), Tekeze, Baro Akobo and Omo Gibe basins, largely occupying the west and south-western parts of the country.

Awash. At this time, it has yet to be established how these authorities will cooperate with the regions on managing water resources, but clearly they will play an important role in basins that are shared by more than one region.

MANAGEMENT OF WATER & ACCESS

Domestic Water Supply

Ethiopia has an estimate population of over 71 million growing at around 3 percent per year. Limited investment in infrastructure means that less than 2 percent of the surface water has been diverted for productive use. As part of the overall planning and policy development of water resources Ethiopia has given highest priority to meeting domestic water needs. However, at a practical level only 23 percent of the rural population has access to water that is considered "adequate", which is defined by the MoWR as at least 20 l/c/day from a well or a capped-spring within a distance of 1.0-km. The WHO standard is 45 l/c/d (WHO, 2000). Even where water supply systems have been developed, many were done so without the participation of the beneficiaries, which has meant that many systems have not been sustained. Presently the water supply for many Ethiopians is either of less-than adequate quality, or requires that it be carried long distances, usually by the young girls of the family, or, in many instances both.

Water in Agriculture

There are four basic categories of irrigation systems in Ethiopia, namely traditional, modern communal, modern private and public, which are estimated to service 60,000, 30,000, 6,000 and 60,000 ha respectively (Lemperiere, 2003).

Traditional Irrigation Schemes: Traditional irrigation has been practiced in Ethiopia for centuries. These indigenous schemes have usually been developed and operated by "water users associations" of no more than 30 farm-families, that depend on either run-of-the-river diversions or springs for their water source, and often include elaborate, locally engineered, labor intensive, capture and conveyance works (Rahmato, 1999). Where the scheme depends on community-constructed diversions, these are frequently washed away with rainy season floods, requiring significant investments in labor by the community during the growing season. In some cases the government and NGOs have helped the farmers by improving the diversion structures.

Water user committees/associations led by elected leaders have long been an integral feature of these schemes, with water allocation, construction, operation and maintenance well organized. Most of these schemes produce crops for community consumption, but some produce cash crops such as fruit, vegetables, and sugarcane. The overall performance (as measured by crop productivity and water use efficiency) of traditional schemes is relatively low.

During the Derg regime, many of these traditional systems were severely damaged when their management was transferred to producer co-operatives. In response to the severe drought of the early 80s, the Derg initiated a program to develop small-scale irrigation, including the "betterment" of traditional schemes. Those users who did not join the co-operative lost their right to water. Even today, many communities remain suspicious of water development because of the association with the collectivisation efforts of the 80s and 90s (Rahmato, 1999)

Even today, approximately 40 percent of the irrigated area is made up of small-scale traditional schemes. According to Rahmato (1999), the operation of these schemes is characterised by equal and equitable access to water. In many areas, decisions are made by water "elders" or "fathers" who are elected to their positions.

<u>Modern Communal Small-Scale Systems:</u> Modern communal small-scale irrigation was initially promoted after the 1974 land reforms and actively encouraged following the 1983 drought. These schemes were developed by the Government or NGOs with beneficiary farmers expected to operate and maintain them. These systems are similar to the traditional schemes with greater investments in infrastructure, and with the water users associations legally recognized. Many of the water users associations have not been effective due, in part, to a lack of involvement in the planning and development of the schemes, but also because the institutional structure was community, at least until recently.

<u>Modern Private Schemes:</u> Modern private schemes were initially developed in the 50s and 60s with foreign investors creating sugar and cotton facilities. Rarely did the implementation of such enterprise involve the local farming population (Rahmato, 1999). This category of irrigated agriculture ceased to exist when the enterprises were nationalized in the 1970s, but has begun to re-emerge in the past ten years through denationalization and the development of new enterprises with long-term leases (around 30 years). The original estates were developed in the upper Awash valley. Currently some 18 modern private irrigation projects are operating in some form over a total area of 6,000 ha. Most are in the Awash, but also in the Rift Valley and the Abbay.

<u>Public Systems:</u> The public systems emerged as a consequence of the afore-mentioned nationalization of private systems and then subsequent development of new schemes. As with the initial development of the private enterprises, these public systems rarely included the local population in planning and development. This category is now diminishing due to abandonment and some privatization. Construction of head works for large and medium-scale schemes may, in principle, be undertaken by the government but the policy is to leave the farm development to the private sector/farmer associations.

Impacts of Irrigated Agriculture Development

Much of the private and public schemes were developed in the lower lands of Ethiopia, where relatively reliable water supplies were and, in many cases, continue to be available. The lowlands of Ethiopia have traditionally been the domain of nomadic and semi-nomadic pastoralists where the social system is based on the clan and inter-clan relationships. Access to pastures and to water for livestock and domestic needs have historically been determined by custom. Given the relatively hostile environment of the lowlands, which includes high temperatures and high risk of malaria, these systems have remained intact for centuries. However, since the 1950s, when the risks from malaria could be better managed, the development of irrigated agriculture in these areas has been promoted, and has led to pressure on the traditional systems, particularly among the Afar and the Arsi in the Awash Valley. Large-scale cotton and sugar plantations developed in the basin through the 1960s and 70s disrupted the traditional grazing lands, migration patterns and access to water. Also, the availability of irrigation water and crops created conflict between the pastoralists seeking fodder and water for the livestock, and the plantations.

Future Developments

Over the past few years, the Government of Ethiopia has undertaken integrated water resources master plans for four of the major river basins in the country and is in the process of developing an updated plan for the Awash valley. These plans have been used as the foundation for the Water Sector Development Plan (WSDP, 2002) that presents a range of interventions to develop, and manage the water resources to meet the social and economic needs of the country. In addition to infrastructure for water supply and sanitation, irrigation and hydropower, the plan includes other interventions such as catchment management, institutional strengthening, and so forth.

The WSDP calls for the development of approximately 274,000 hectares of additional irrigation within the next 15 years equally divided between small-scale, community based systems, and medium and large scale developments, which would include the private sector. This would more than double the present irrigated area. Hydropower is also included in the WSDP, and would provide most of the energy to meet Ethiopia's needs for the next 15 years and, under the Nile Basin Initiative, could provide considerable power for export.

With the reorganization of Ethiopia into regions and the decentralization of decision making to the regional level in the 1990s, decisions regarding access to water, at least for major investments, are now being made at the regional level. For example, in the new region of Afar region, which includes the lower Awash basin, the local pastoralists are now developing their own irrigated cotton operations. However, given that water is already in relatively short supply, these new developments are impacting the plantations that were previously developed and managed by the Government (Developments, 2004).

Rights to Water in the Context of Future Development

As Ethiopia continues to develop it water resources to meet the social and economic needs of its population, there is a need for water related legislation that will, among other things, establish water-rights, and set tariffs and charges (Rahmato, 1999). As with land tenure, if communities or investors do not have a sense of security with regards to water rights, then the necessary improvements for effective water management will not be made. Gebremedhin and Peden (2003) argue that secure water rights and the supporting legal framework are pre-requisites for the sustainable development of irrigated agriculture.

As presented above, there has been a long history of effective water rights systems at the community level. However, rather surprisingly, there is limited information available on these indigenous systems except that many of them were disrupted during the 1970s and 1980s by attempts to "improve" the management of the traditional irrigation systems. Today water rights disputes are generally dealt with at the community or water user association level (CRS, 1999), but the effectiveness depends on the communities understanding of their water rights and responsibilities, and their capacity to effectively implement these, which is often lacking. Furthermore, the capacity at the Federal and Regional level to deal with property rights, including water, is very limited (Kamara and McCornick, 2004).

Allocation of water rights to medium and large-scale irrigation enterprises has been practiced for over four decades, although again these systems have been subjected to changes in Government policy. Now allocation of water rights to many of these systems has been devolved to the region. However, under the WSDP (MoWR, 2002), some of the larger projects are to be implemented by the Federal Government.

SUMMARY & CONCLUSIONS

It is striking that although there is clearly a wealth of experience of managing and allocating water at the community level within traditional irrigation systems, there is a dearth of information, at least in published literature and documentation that is currently available in Ethiopia.

The right to water in Ethiopia is complex, and it has been disrupted due to major changes in the political environment. As the country continues to develop and right the wrongs of previous interventions it is important to ensure that both the communities and the potential investors have the necessary security of their right to water.

Despite prioritizing domestic water supply in the National policies, at the individual and family levels, many Ethiopians have limited access to adequate water resources to meet their basic needs.

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THE IMPERIAL VALLEY-SAN DIEGO WATER TRANSFER AGREEMENT: A CASE STUDY OF PROPERTY RIGHTS IN COLLECTIVE ACTION

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ABSTRACT

Taking a social capital approach, this paper examines the negotiation strategies leading to the Imperial Valley-San Diego Water Transfer Agreement between Imperial Irrigation District (IID) and the San Diego County Water Authority (SDCWA). Adopted in October 2003, the transfer will result in the largest sale of water from farms to cities in the United States. On this agreement depended a series of legal contracts including California's Colorado River Quantification Settlement Agreement (QSA). In the main, social and institutional factors shaped the substance of the transfer agreement. The primary factor was preservation of IID's water rights for the reasonable and beneficial use of water. Other factors related to a community's legal right to water as property supporting a way of life and the impact of the water transfer on IID's ecological commitments to the Salton Sea. A contentious series of negotiations culminated in an IID legal filing against the United States Department of Interior in January 2003. In the Imperial Valley, water as a property right and collective action mobilized to protect said rights by the IID Board of Directors are examined to show how they influenced the ultimate outcome.

INTRODUCTION

This case study is illustrative of property rights defined as the capacity to mobilize the collective to stand behind its claim to a benefit stream (Bromley: 1991) and used by the Collective Action and Property Rights (CAPRi) Program of the Consultative Group on International Agricultural Research. More significantly, it is a case of property rights in action as social capital. Lin (2001) identifies three critical components for analysis of social capital. First, how the resources take on value and how valued resources are distributed (water rights). Second, how individual actors use interactions and social networks that are differentially accessible. Third, how access to such social networks is mobilized.

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The significance of property rights and social capital are examined through this case where the symbolism of water was mobilized for community action by the Imperial Irrigation District (IID), Imperial Valley in order to protect its rights to Colorado River water under the California 4.4 Plan.

IMPERIAL VALLEY, CALIFORNIA: THE CONTEXT

Imperial Valley, located in the southeastern corner of California, is part of the arid American west where water is scarce. Imperial Valley receives, on average, three inches of rainfall annually.

Under the California Water Code, water is owned by the State and individuals have the right to use that water. In the United States and California, water rights are a form of property rights, which cannot be taken without compensation. Use of Colorado River water in the Imperial Valley adds another wrinkle. Originally, settler-owned companies brought Colorado River water into the valley from outside the State boundary. Over time, with the involvement of the federal government through the United States Bureau of Reclamation (USBR) these water rights became vested to the Imperial Irrigation District (IID) as a public trust. Under the California Water Code, water use was limited to what is reasonable and beneficial. The federal Law of the River contains similar conditions.

Before the diversion of water to the valley in 1892, there was no settled agricultural community. From 1892 onwards, first through the Colorado River Irrigation Company, and subsequently the California Development Company in association with the South Pacific Railway, land developers attempted to bring the waters of the Colorado River to the Imperial Valley. The personal and financial hardship faced by the pioneers and their vision to reclaim the desert succeeded under George Chaffey, an engineer with years of experience in irrigation development in the deserts of Australia.

Chaffey named the region the Imperial Valley and declared that "everything is alright." However, increased canal siltation and fear of reduced water supplies to the Imperial Valley farms prompted the canal company to construct a second intake from the river. This intake would be used during the periods of water shortage and closed during the flood season. Therefore, it was built without a control gate. A series of floods from 1904-1906, particularly the flood of 1905, saw the entire flow of the river passing through the second intake. Flows to the Imperial Valley (the Salton Sink), filled the Salton Sea, which is 300 feet below sea level and currently maintained through IID and Coachella Valley Water District (CVWD) drainage.

THE SYMBOLISM OF WATER

In capturing, controlling, and diverting water where it was not naturally available, and in building a permanent agrarian community where there was none, the common goal of the settlers was expressed in the term "betterment." Betterment depended on protecting rights to the water from the Colorado River, for "without water this land would again become desert" (Imperial County Historical Society).

IID's rights to the Colorado River water began when the California Development Company appropriated approximately seven million acre-feet per year (MAFY) of water under California law. These rights were later bought by the Southern Pacific Company and transferred to IID in 1914. The 1922 Colorado River Compact among the seven states sharing the river's water (Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming) was negotiated by the United States government through the Department of Interior. IID, without waiving its original water rights, agreed to the settlement which allotted California 4.4 MAFY plus 50 percent of any surplus water. Of these, IID's right to Colorado River water delivered to California totaled approximately 3.4 MAFY.

IID AND THE IMPERIAL VALLEY

In 2001, with an irrigated area of 462,202 acres, IID celebrated 100 years of bringing water to the Imperial Valley. Its five-member board is elected by the public at large (one-person, one vote). Of IID's delivered water (all from the Colorado River), 98 percent is used for agriculture. IID also generates and delivers electricity. Since 1936, IID has expanded its energy delivery to become the sixth largest energy supplier in California, serving over 98,900 customers. As a consumer-owned utility, IID holds legal title to its appropriative water right, which is defined as property that the district holds in trust for its use and purposes (California Water Code: Sec. 20528, 20529, 22437).

As the purveyor of water for a one-billion dollar agricultural industry, IID and its community have weathered many changes over time. At the time of the present water dispute, IID transported around three MAFY from the Colorado River, delivering about 2.7 MAFY to farmers who pay $16 per acre-foot. Imperial Valley farmers, charged with overuse water (5.5 AFY per acre in comparison to the Central Valley farmers at 3.5 AFY), point out that they harvest three crops per year as opposed to two in California's Central Valley. Furthermore, the Imperial Valley, with an average of three inches of rainfall per year, has little effective precipitation and no usable groundwater. Currently, IID water is used primarily to produce field crops, livestock, vegetables and melons.

With 55 percent of the land farmed by tenant farmers, absentee landlords have bought farmland hoping to cash in on the benefits of potential water transfers to urban areas. The greatest misstep in this context was by the Bass brothers, members of a Texas oil family, who bought 42,000 acres of farmland in the Valley, which they subsequently sold to US Filter, then a subsidiary of Vivendi Environment. The Bass brothers surreptitiously negotiated with representatives from the coastal City of San Diego for sale of the water required to farm this land, unaware that only IID as the property owner of the water could transfer the Valley's Colorado River water. IID retains its water right at the termination of any water transfer agreement (California Water Code: Section 1011).

The Bass brothers' activity created distrust on the part of Valley dwellers toward urban San Diego. That distrust is compounded by the fact that some farmers in the Imperial Valley were uprooted from the Owens Valley. The story of how Los Angeles and William Mulholland "stole the waters" of the Owens Valley farmland and diverted it to build the city of Los Angeles is well documented in text (Reisner: 1986) and in film (Chinatown).

Colorado River Legal Framework

The collection of laws and agreements among the beneficiary states of the Colorado River and with the federal government is known as the Law of the River. The United States Secretary of the Interior is the Water Master with authority over Colorado River.

In 1922, the USBR estimated the average annual flow of the Colorado River at 17.5 MAF. Under the compact, this water is divided between the states in the Upper (Wyoming, Utah, Colorado, and New Mexico) and Lower (California, Arizona, and Nevada) river basins, with the Upper Basin required to deliver 7.5 MAFY to the Lower Basin. Mexico was also allotted 1.5 MAFY.

In 1928, after contentious dialogue among the states, the United States Congress initiated ratification of the Colorado Compact. Under this agreement, California was allotted 4.4 MAFY of Colorado River water, with an additional right to 50 percent of any declared surplus water. Arizona was allotted 2.8 MAFY and Nevada 300 thousand acre-feet per year (KAFY). Over time, because Arizona and Nevada did not use their allotment, California came to use 5.2 MAFY. However, in the early 1990's both Arizona and Nevada began to use their full entitlement.

In 1992, during negotiations among the Compact States, what came to be called the California 4.4 Plan (4.4 Plan) was proposed. Under the 4.4 Plan, beginning in 2000 and over the next fifteen years, California would come to live within its annual allotment of 4.4 MAFY (plus 50% of any declared surplus) of water by progressively reducing its use by 20% from 5.2 MAFY to 4.4 MAFY. Ultimately, the California 4.4 Plan depended on three California agencies that hold rights to Colorado River water entering into what came to be called a Quantification Settlement Agreement (QSA).

The QSA, the Transfer and the Environment

IID pressed for approval of the water transfer under the provisions of the California Water Code. Metropolitan Water District of Southern California (MWD), which supplies water to the San Diego County Water Authority (SDCWA), and Coachella Valley Water District (CVWD) argued that it was an exclusively federal issue, since federal signatures were required (USBR: October 2003). IID and CVWD held rights based on reasonable and beneficial use, without specific apportionments, while MWD rights were quantified at 550 KAFY plus unused agricultural deliveries. The agencies each had minimal or no return flow to the Colorado River.

Because a major share of the water from the Colorado River was diverted for use in the Imperial Valley (up to 3.1 MAFY), the centerpiece of the QSA was the IID/SDCWA Water Conservation and Transfer Agreement, which was signed in April 1998, with the approval of the State. Ultimately, for this transfer to go forward, both MWD, which held a junior water right to IID and controlled the aqueduct that would convey the transferred water to San Diego; and CVWD, which also held a junior water right to IID, had to sign on to the QSA.

Negotiations on the QSA were begun once the transfer agreement was signed; and in October 1999, the districts agreed through consensus that IID could transfer the water without relinquishing its senior prior water rights. The transfer was to start at 20 KAF, increasing by 20 KAFY until IID was transferring 200 KAFY to San Diego. The transfer agreement had an initial term of 45 years with an option to renew for another 30 years. For the SDCWA, this agreement would ensure a reliable supply of water to an area with minimal local water supply, which is dependent on MWD for imported water.

The transfer agreement was contingent on IID's completion of an Environmental Impact Review and Environmental Impact Statement under the California Environmental Quality Act and the National Environmental Policy Act, and the agreement of Valley farmers to undertake conservation programs to save the required amount of water. However, federal interpretation of reasonable and beneficial uses was in contradiction with the State requirements for environmental protection related to the Salton Sea.

IID agreed, through negotiation, to continue its drainage discharge of about one-third of the Valley's water – nearly 1 MAFY – to the Salton Sea (which otherwise would more rapidly become too salty for fish and birds) for the first 15 years of the agreement. Under the Law of the River, the amount of IID's use not required for sustainable agricultural production was considered by some to be non-beneficial. A compounding factor is that Colorado River water delivered to IID growers' ranges from 750 to 950 ppm of salt and the Imperial Valley sits on the remains of a salt sink. Therefore, farmers are correct when, to quote Hettena (2003), they say they excess water, in part "to wash salt from the soil."

Under the QSA and other associated agreements, the following issues had to be signed off on: IID would be responsible, through fallowing, for mitigation of environmental impacts within Imperial County and to the Salton Sea for the first fifteen years of the agreement. By December 31, 2006, the California Secretary of Resources must decide if a feasible restoration alternative exists for the Sea or if it should be left to die. IID would be compensated at the rate, varying over the years and with the market, from around $258 to $400 per AF for water delivered into the MWD's Colorado River Aqueduct for delivery to the SDCWA. San Diego was to invest two billion dollars to buy the water, which would include payment for the socio-economic costs of fallowing. The California agencies, under pressure from the Colorado Compact states, as well as State of California and federal agencies, agreed to finalize an agreement by December 31, 2002.

UNRAVELING OF A SETTLEMENT

The Imperial Valley community was responsive to an efficiency-based transfer. But, once fallowing was introduced as a requirement, the public became apprehensive. As the deadline for ratification of the Agreement approached, this and other issues emerged, resulting in IID refusing to ratify the Agreement. The following are some highlights of the sequence of events:

In August 2000, a proposal was made by the Salton Sea Authority to use Colorado River water to reduce the salinity of the Salton Sea, which is a crucial stop for migrating birds. This proposal was dropped due to opposition from other water agencies that rely on Colorado River and from environmentalists wanting to use the river water to revitalize the wetlands in Mexico (Associated Press: 2000). In June 2002, the Center for Biological Diversity reported that the transfer of water would result in the demise of many species in the Salton Sea, which is presently 25 percent saltier than ocean water. This conclusion was based on the fact that the conservation-based transfer would reduce runoff to the Sea. At this point, the proposal to fallow 75,000 acres of farmlands was introduced.

This was the turning point. Both the transfer negotiations and community sentiment about the proposed water transfer became highly charged with emotion. Evidence from the sources all pointed towards the following key issue – fallowing would lead to loss of jobs and the destruction of a heritage.

After marathon negotiations, during which California State Assembly Speaker Emeritus Robert Hertzberg threatened to stir up farm worker unions and put farmers out of business and even legislate the water board out of existence if the deal were not concluded (US News Online: 2002), IID unveiled a proposal to California Governor Gray Davis to fallow 20,000 acres of land over a five year phase-in and five year phase-out process. After this IID would unconditionally return to a conservation-based plan.

The community's reaction to the transfer agreement became increasingly vocal. The principal point of contention was the Valley's responsibility to the Salton Sea, with mitigation costs given at $300 million to one billion dollars. Because neither the federal or State government had come up with a long-term plan to protect the Sea after the fifteen years of IID's responsibility under the proposed agreement, the community was concerned that it would be indefinitely saddled with this responsibility and cost.

Related to this was the fear that, once fallowing was required, it would lead to more fallowing and the demise of the agrarian way of life. This is evident in a statement by Board President Stella Mendoza, "This community is different, it is not a [water] tap, (and) people talk about their heritage. ... We get three inches of precipitation annually and only a tenth of an inch last year. Without water there is no life" (author interview).

Perry (2002), an *LA Times* reporter, notes that in addition to the concerns of the Salton Sea, IID and Imperial Valley residents were concerned about third party economic impacts within the community. Socioeconomic concerns included the impact of fallowing on farm income, unemployment among farm workers, and the impact of both on income of ancillary service providers to agriculture, local businesses and community services.

In December 2002, the stakes in the water dispute were raised when the Assistant Secretary of the Interior, Bennett Raley, attempted to cut IID's water allocation by about 800 KAFY. Coincidentally, this was the amount needed for California to reduce its use to 4.4 MAFY. Raley cited IID for non-beneficial use of about 5 percent over the per-acre limit set by a 1997 Supreme Court Decree. On December 9, 2002, after seven years of negotiations, IID with this looming threat by the Interior Department defiantly rejected the proposed agreement.

In *Imperial District Sues Department of Interior to Defend Water Rights* (IID Press Release: 2003), IID states that the Department of Interior was "... not honoring existing water rights and violating IID's water rights by its attempt to unilaterally impose an unlawful reallocation of Colorado River water to more junior right holders... motivated and designed to placate powerful urban southern California at the expense of Imperial Valley agriculture." IID obtained a temporary injunction preventing the USBR from reducing IID's 2003 water order by 800 KAF.

IID Board President, Stella Mendoza was quoted (Perry: 2002), "If you push me around, I'll push back. We'll see them in court. I'm willing to [have IID] pay for our defense. Without water, Imperial Valley is nothing."

SIGNING THE QSA

The IID Board finally gave its approval in October 2003. On October 10, 2003 the agreements and documents needed for the QSA, the water conservation and transfer arrangements, and the settlement of various matters of litigation were signed. For a summary, see *Quantification Settlement Agreement and Related Agreement Letter from Lloyd Allen* 10/29/03 (Allen: 2003). Signing of these agreements made possible the nation's largest farm to urban water transfer. In the ten months between when IID filed suit against the Department of Interior and the signing of the QSA the following issues, among others, were negotiated and resolved:

IID's water rights remained unchanged, with only conserved water to be transferred. However, a transfer strategy that was to be based on conservation became a transfer based on fallowing for the agreement's first 15 years. By year fifteen and through the duration of the transfer, system improvements such as canal interceptors, mid-lateral reservoirs, and automation along with on-farm improvements such as tailwater recovery systems and micro-irrigation are expected to provide the water needed for the transfer. Table 1 indicates the parameters of the transfer schedule – in Year 1, 10 KAF to San Diego plus 5 KAF mitigation fallowing, equal 15 KAF fallowing; in Year 15, all 150 KAF fallowing is mitigation water; from Year 16 on, there is no mitigation or fallowing.

In addition, protracted and expensive litigation were eliminated, with the Department of the Interior approving IID's 2003 Water Order and IID dismissing its lawsuit against the federal government, while preserving all of IID's rights, claims, theories and defenses in future litigation between IID and the United States.

Table 1. Compromise IID/SDCWA Transfer and QSA Delivery Schedule (KAF).

Year		IID Delivery to		Total	Fallowing	
		SD	CVWD	Efficiency	Mitigation	Total
1	2003	10	0	0	5	15
6	2008	50	4	4	25	75
15	2017	100	45	145	150	150
16	2018	130	63	193	0	0
27-45	'29 – '47	200	103	303	0	0
46-75	'48 – '77	200	50	250	0	0

Source: *Revised Fourth Amendment* to the IID/SDCWA Water Conservation and Transfer Agreement (QSA, 2003, Exhibit 1).

The impact of the community voice in shaping the final outcome becomes clear in the way apprehensions were dealt with regarding IID's responsibility to the Salton Sea under State and national environmental protection laws. IID was responsible for maintaining the Sea for the first fifteen years. The State had a "no take" rule to protect endangered species, but new State legislation was passed to allow IID a limited take of fully protected species. Further, the State would pay $50 million to IID for water used to maintain the Sea during the first 15 years of the transfer, pick up environmental costs above $133 million – the amount to be contributed by IID, CVWD and SDCWA, and pay for long-term Salton Sea restoration, if determined feasible.

The positive impact of IID decision-making in December 2002 is even more evident when considering issues related to the social impact of the transfer. With the active participation of a 20-member Citizens Advisory Committee and involvement of the IID Board, three new sections that protect IID and valley residents were included in the QSA *Revised Fourth Amendment to the IID/SDCWA Transfer Agreement*, as follows: Section 14.3 - Protection of IID Water Rights; Section 14.4 - Fallowing Protection for IID; Section 14.5 – Mitigation of Socioeconomic Impacts Caused by Land Fallowing. Section 14.5 sets aside $20 million for mitigation of third party impacts over the project's life and establishes a Local Entity, which is functioning, to oversee disbursement of this money. Socioeconomic impacts of fallowing will be measured using a regional economic model. Disputes concerning funding and/or socioeconomic impacts will be resolved through binding arbitration. (Quantification Settlement Agreement: October 2003.).

Through its Emergency Fallowing Program, in which 5,764 acres were fallowed to produce 31,497 AF at an average cost of $56.35/AF, IID obtained the water needed to meet its QSA obligations for 2003 and part of 2004. On February 5, 2004, the IID Board adopted a resolution "authorizing the execution of the agreement of purchase" by IID of 42,000 acres of farmland owned by Western Farms, a holding of US Filter (IID Board Resolution: 2004). IID will likely use this land as a hedge, by control of fallowing, to manage its QSA commitments with minimum impact on the community (IID Press Release: 2004). The land is in escrow, with an expected purchase date of May 2004.

CONCLUSION

In Imperial Valley, CA, the history and traditions of the pioneers, the historically and legally established system of priority rights, the interests of the community at large, and the rural-urban values were tapped when the community was faced. The community rallied to preserve its rights to water.

Legally, the resource belonged to the community as a whole, as did its benefits. Unlike other resources with a market value, the community saw the value of water in both its symbolic (way of life) and monetary (dollars per acre-foot) value. The Imperial Valley case illustrates that water becomes available for transfer, even in a market-oriented society, only through a gradual and negotiated social transformation with considerations of equity.

Secondly, the case illustrates how individual actors mobilize social networks to achieve their constituencies' common goals. As the President of the IID Board, Stella Mendoza along with the other Board members mobilized the support of a sizable segment of the traditional farming families, the Latino population of farmers and agriculture-based workers, and other residents supporting the agrarian vision for the Valley.

In satisfying the third component of social capital regarding how resources were mobilized, the IID Board mobilized the symbolic, legal and financial resources of IID for the successful conclusion of the water transfer agreement and preservation of its water rights. When uncertain factors crept into the negotiations (the duration and cost of IID's commitment to preservation of the Salton Sea, and whether fallowing would be required, as a result, and to what extent), the Board accessed the resources of its institution. For example, as a public utility holding the water right in trust, IID has many ways in which the public can have access to the proceedings of negotiations. These were fully tapped through public meetings, the Internet and the news media. Phrases such as "senior rights," "third party impacts," "reasonable and beneficial use of water," and "fallowing" became more than words, they became emotionally charged symbols.

Their background and public reference to what farming meant to the community and its Board members as well as then-Board President Mendoza's empathy with the public, were added bonuses. Backed by public support, historical precedents, and legally established rights, IID forced the hand of the United States and State governments, requiring them to evaluate water transfer in terms other than growth engineered benefit for one entity.

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MEETING CHANGING WATER DEMANDS IN THE DESCHUTES BASIN OF CENTRAL OREGON

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ABSTRACT

Oregon's water rights system allocated water in the Deschutes Basin primarily to irrigation without placing adequate safeguards on maintaining instream flows for environmental purposes. Provisions of state law regarding instream water rights, however, lay a framework for various activities aimed at restoring flow in the river. These include provisions that allow water rights transferred instream to carry their original priority date, require new groundwater rights to be mitigated and require government financed piping projects intended to conserve water to put a percentage of the saved water instream. Efforts of groups like the Deschutes Resources Conservancy and the Tumalo Irrigation District demonstrate that public participation and collaboration among government and non-government agencies can succeed at working creatively within the existing legal system to meet the goals of conservation, municipal and traditional agricultural users.

OVERVIEW

The Deschutes Basin, the second largest basin in Oregon, collects snowmelt and rainfall from the eastern side of the Cascade Mountains along a 170 mile corridor in Central Oregon, ultimately draining into the Columbia River (See Figure 1). The basin is known for its outdoor recreation. Sport fisheries for trout and salmon are world-class. Hunting, hiking, camping, golf and skiing contribute to the economy and quality of life and attract new businesses and residents to Central Oregon. Agriculture, while declining in economic importance, is still an essential way of life for many. Irrigation, which is necessary in this high desert climate, is the highest consumptive user of water in the basin, although demands for municipal use and restoration of instream flows are growing.

This paper examines the evolving uses of water in the basin, the challenges faced in balancing traditional agricultural demands with other demands and community responses to utilize more efficiently the limited resource. The paper highlights case studies which illustrate community responses. These include leasing water rights from irrigation users, groundwater mitigation and piping irrigation canals.

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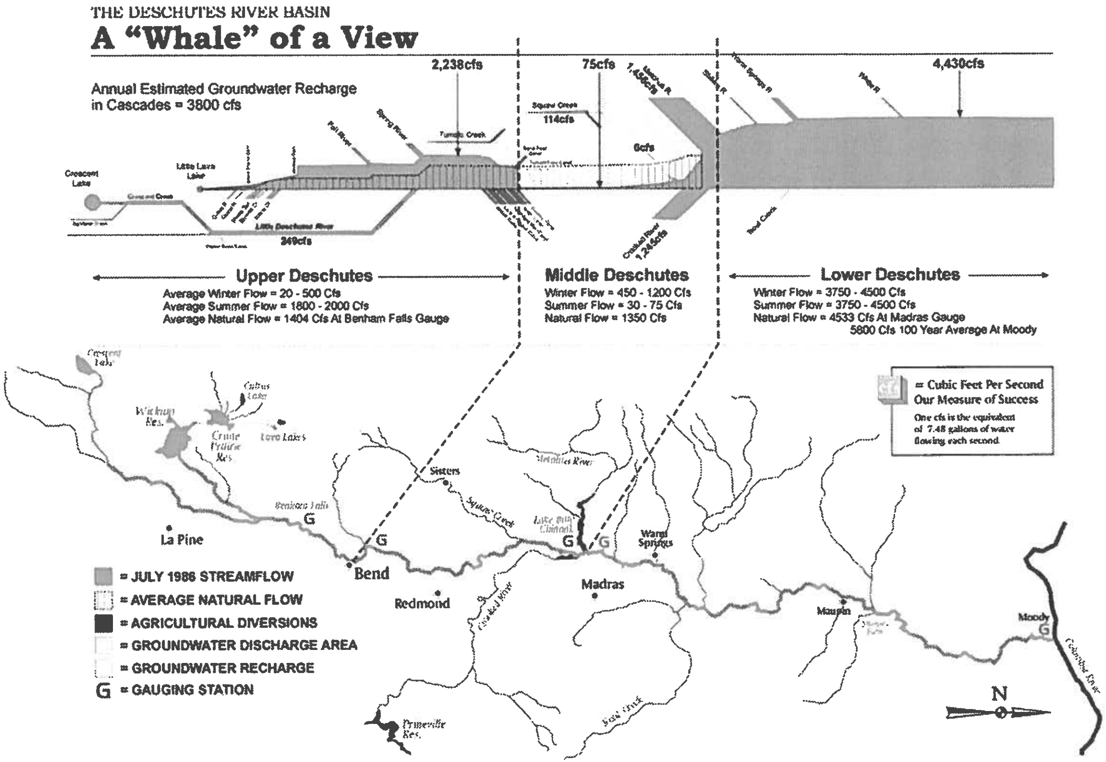

Figure 1. Streamflow in the Deschutes Basin
Original by Bob Main, OWRD, modified by Patrick Griffen, City of Bend, used with permission

Irrigation Development

Initial settlement of the Deschutes Basin began in the 1870s, with livestock raising the principal livelihood of the earliest settlers. The Carey Act of 1894 provided a method whereby settlers could acquire lands from the public domain if they irrigated a portion of their claim. The intention in Oregon was that the State would give private irrigation developers a lien against the lands and those private investors would raise the capital, take the risks and collect the profits. Once the irrigation system was in place, the settler could file a claim for his land. Unfortunately, the developers were more interested in quick profits than in actual development, and often the water systems were not properly constructed leaving the settlers without reliable water (Claeyssens, 2004). The Tumalo Project, discussed in the second case study, attracted settlers to the area west of Bend in the early 1900s. After years of financial, managerial and engineering disasters it was taken over by the state in 1913, and eventually turned back to the Tumalo Irrigation District without indebtedness (Winch, 1984).

Despite rampant speculation and overly optimistic expectations from irrigation development in the Deschutes Basin, canals and reservoirs continued to be constructed throughout the 20th century. Today six major canals divert water from the Deschutes in or near Bend. Federal involvement began in 1939 with the re-construction of Crane Prairie Dam and the construction of Wickiup Dam, which resulted in water flowing 65 miles north to irrigate farms near Madras in Jefferson County (Johnson, 2003).

While domestic use is growing rapidly, it still only accounts for one per cent of total water use in the basin. Irrigation continues as the major water use, accounting for 95% of all uses.

Despite the magnitude of water used for irrigation, production of irrigated crops is a relatively minor portion of the regional economy. In 1997, the total value of agricultural products including livestock sold in the three county Central Oregon area was $97 million. By contrast the value of manufacturing goods produced was $1.3 billion. Irrigation is the predominant agricultural activity, with 164,326 irrigated acres representing 75% of the total cropland (USDA, 1997). Of the total of 2155 farm operators, only 42% reported farming as their principal occupation. In one irrigation district in Deschutes County the average size of holdings is now 6 acres (Arnold Irrigation District, 2000). A new agricultural landscape is emerging in the Deschutes Basin, characterized by smaller farm units, more part time farmers, and production concentrated on hay and pasture.

Hydrology and Water Quality

The Deschutes River in its natural state is characterized by its remarkably stable flow (Gannett, et al., 2001, O'Conner, et al., 2003) resistent to both drought and flood. The upper Deschutes River watershed encompasses that portion of the Deschutes Subbasin upstream from Lake Billy Chinook 132 miles to its headwaters in the Cascade Mountain Range (See Figure 1). Water storage and releases drastically alter the natural flow regime of the Deschutes River. Crane Prairie and Wickiup Dams regulate flows in the upper Deschutes River. As a result, the stable natural flows in the Deschutes above Bend have been replaced with flows as low as 20 cubic feet per second (cfs) below Wickiup Dam in the winter months when the reservoirs are being filled and as high as 1,600 cfs when water is being released from the reservoirs in the summer months. Flows released out of Wickiup increase downstream with inflows from groundwater, springs and the Little Deschutes River above Bend.

Nearly all water released from Wickiup Reservoir during the irrigation season is diverted into six major irrigation canals. River flow below the diversion points during the summer is very low. Until recently, summer flows dropped to about 30 cfs but leasing, canal lining and piping are all contributing to efforts to increase streamflow below the diversions.

Despite the extensive diversions upstream, the hydrograph for the lower Deschutes River has not changed substantially from pre-European settlement to today. The lower river experiences only small seasonal variations in discharge due to groundwater, which is estimated to contribute 80% of the flow at the mouth. Near the confluence with the Columbia River at the Moody gage, the flow averages 5,739 cfs with ranges from 4,290 to 7,380 cfs (O'Connor, et al., 2003).

Water quality problems exist in several reaches of the Upper Deschutes River and tributaries, with seasonal temperature extremes, high erosion rates, and low dissolved oxygen being the major problem parameters. The Oregon Department of Environmental Quality has instituted standards which are fish specific, based on water quality requirements of species at specific stages of their lives. For example, the reach of the Deschutes above Steelhead Falls exceeds the water temperature criterion for salmonid spawning (September 1 through June 30) and rearing. The highest recorded water temperature for the reach was 81°F in 1994. Low flows are the main cause of elevated water temperatures and contribute to nutrient concerns, as do agricultural return flows and the lack of riparian vegetation. In the Lower Deschutes summer water temperatures often exceed temperature standards for salmonid rearing and spawning.

WATER LAW

Oregon Water Law

In 1909, Oregon adopted a water law similar to laws in other Western states based on prior appropriation. The Oregon law provided for settlement of water disputes in the courts and thus any water right initiated prior to 1909 is determined in a court process of adjudication. While all water rights in the Deschutes Basin have been adjudicated, the process in the Klamath Basin, for example, is still going on and is a major cause of conflict. The four major principles of the 1909 Oregon Water Code are that water belongs to the public, any right to use water is assigned by the state, older rights take priority over newer rights and water must be used for "beneficial" purposes and cannot be wasted (OPB, 2001). Oregon has an abandonment and forfeiture provision stating that any water right not used over a five-year period is subject to forfeiture. With State approval, water rights may be transferred to other uses or users or in point of diversion providing the proposed change causes no injury to other water rights.

Similarly to other western states, Oregon did not specifically define "beneficial use" or "waste" and this has been left to interpretation by the courts. Generally the definition has been very broad and there is wide disagreement among interests as to what constitutes beneficial use.

Although water allocation is a state matter, in some cases federal laws have been seen to "trump" state water rights. The Endangered Species Act (ESA) has been used in some cases as justification for overriding existing private water rights. According to a prominent water lawyer, private property rights have been bounded and superseded by Public Trust obligations, although the tension between the two has been fertile grounds for lawsuits (Spain, 2004). Events in the Klamath Basin serve as a sobering example, where irrigators were initially shut off in order to meet requirements for downstream salmon although later compensated for their losses.

The Legal Framework for Deschutes Restoration

Virtually the entire flow of the Deschutes was allocated to water rights by the early 1900s. Technically, the entire flow of the river could be diverted to meet demands of water rights holders, although water managers have agreed informally on minimum flows and maximum rates of change in flow for environmental purposes. In 1983, in recognition of environmental concerns, Oregon issued instream water rights for the Deschutes River from Wickiup Dam downstream to North Canal Dam. Since these are junior to existing water rights they are frequently not met.

Under state law, water rights that are purchased, leased or gifted and transferred to instream rights retain their original priority date. This provision provides the basis for leasing or purchasing water rights from agricultural users and transferring those rights to instream uses, as is being carried out by the Deschutes Resources Conservancy, described in the first case study.

A total of 147.3 miles of stream within the Upper Deschutes Watershed are included in the National Wild and Scenic Rivers program and several segments of the Deschutes River have also been designated as State Scenic Waterways. The Lower Deschutes and several reaches of the Crooked River have been designated under both federal and state programs. These designations have had a serious effect on the way the State has issued recent water rights. The scenic waterway laws (ORS 390.805 et seq.) prohibit the state from issuing any new water rights in or above a scenic waterway if the impact, either individually or cumulatively, is greater than one percent of the average daily flow or one cfs, whichever is less. Consequently, only a few surface water rights have been issued since 1988. Any new groundwater right that is hydraulically connected to the Deschutes River has to provide mitigation before the water right permit is issued.

The Conserved Water Act of 1973 and subsequent statutes provides for the reallocation of water saved from conservation projects such as piping. The percentage of saved water that may be applied to new uses or lands depends on the percentage of state or federal funding contributed to the conservation project but federally funded projects that are submitted to the Oregon Water Resources Department for conserved water must return a minimum of 25% of the documented, saved water instream. This law provides the basis for transferring saved water to instream uses and is the stimulus for undertaking piping projects in the Tumalo Irrigation District and elsewhere in Oregon.

These three provisions of state law, that transferred water rights carry their original date, that new groundwater rights require mitigation and that government financed piping projects must return a percentage of conserved water to the river, create the framework for the activities described below to restore flow in the Deschutes Basin.

CASE STUDY:
LEASING AND MITIGATION PROGRAMS

The Deschutes Resources Conservancy (DRC) is a private non-profit corporation authorized by Congress to receive technical assistance and financial support from federal agencies to support ecosystem restoration in the Deschutes Basin. The DRC was founded by the Confederated Tribes of Warm Springs, seven local irrigation districts and Environmental Defense to bring together water users and managers in one institution dedicated to collaborative watershed restoration. Through its programs, the DRC employs voluntary, market-based methods to facilitate the reallocation of water more efficiently throughout the Basin, resulting in both direct and indirect streamflow restoration. The DRC administers several enterprises which use different methods to restore streamflow. These include a Project Grants Program, which has implemented over 50 streamflow and water quality restoration projects, a Riparian Restoration Program which revegetates riparian areas to improve habitat and water quality, and the Deschutes Water

Exchange (DWE) which operates the leasing and groundwater mitigation programs profiled below as well as brokerage and administrative services.

Annual Water Leasing Program

The DWE program to acquire water for instream flows aims to restore natural flows in dewatered streams, allowing for the protection and restoration of habitat for fish and wildlife. In its seventh year of existence, the Annual Water Leasing Program (AWLP) is slated to add more than 75 cfs to the Middle Deschutes during the 2004 irrigation season, comprising 30% of the 250 cfs streamflow target for this reach (See Figure 2). In 2003, the AWLP leased 52 cfs in the basin, doubling previous annual summer flows. Leasing is an extremely cost-effective and immediate solution for putting water back instream; in 2003 the combination of donated and paid leases enabled the DWE to lease water instream for less than $6 per acre-foot on average. Since the leased water maintains its priority date, the result is that increased flows in the Middle Deschutes are assured.

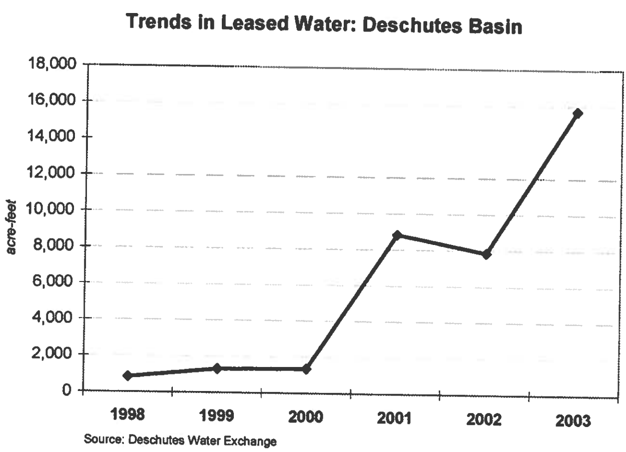

Figure 2. Progression of the Annual Water Leasing Program

The DWE has also experimented with different methods of encouraging participation in the leasing program. After noticing that participation varied greatly across irrigation districts, in 2003 the DWE decided to test a reverse auction methodology in the Ochoco Irrigation District to determine the degree to which price affects participation. The DWE set a secret reserve price of $75 per acre (equivalent to about 3 acre feet of water at the farmer's headgate in this district) subject to a $50,000 budget constraint. Potential lessees submitted price/quantity bids; three of eight bids fell below the reserve price and were accepted. A total of 196.9 acres was leased for $10, 492.90. The exercise was repeated in February 2004, with the secret reserve price raised to $91 per acre. In this case, all nine bids submitted fell below the reserve price and were accepted. A total of 647 acres was leased instream at a cost of $43,433.00. Interestingly, the average bid price fell from $75.81 per acre in 2003 to $63.20 per acre in 2004 and the range of bids collapsed from $29-$108.50 per acre in 2003 to $29-$85 per acre in 2004. These results indicate that irrigators engaged in strategic behavior to ensure their bids were accepted. The reverse auction is a valuable method for eliciting a price signal where there previously was none.

The AWLP benefits irrigation districts, water right holders and conservation interests by providing a vehicle that preserves the beneficial use of water, allows for water right holders to capture some value from their asset when they choose not to irrigate, and benefits streamflow and water quality. However, despite the attractive qualities of leasing, it remains a short to medium term solution. The DWE has found success with introducing multi-year and five-year opt-out leases, but the most desirable are permanent instream transfers. Permanent transfers are difficult to acquire, however, since individual water rights are uncommon in the Basin and irrigation districts are reluctant to release water rights outside of the district due to concerns about assessments. Nevertheless, leasing serves as a valuable introduction to water rights management for water right holders and often proves to be the catalyst necessary to engage in permanent instream transfers.

Groundwater Mitigation

The DWE also facilitates transfers from surface to groundwater which results in water permanently added to Basin streams. Groundwater mitigation is necessary because the Oregon Water Resources Department now requires any new groundwater right to be offset by transferring an existing surface water right instream. Given Central Oregon's current and projected population boom, cities and quasi-municipal entities may require the equivalent of up to 3225 acres of irrigated land in the next 20 years to offset their groundwater needs (City of Bend, 2004). In February 2003, the Oregon Water Resources Commission awarded the State's first Groundwater Mitigation Bank charter to the DWE. In 2004, the DWE offered for sale the first temporary mitigation credits in the basin and is currently planning the first auction of permanent credits. The DWE also provides mitigation services to individual clients on a fee-for-service basis. These services include assistance both in establishing mitigation credits through mitigation projects and procuring credits to fulfill a mitigation obligation. Often these services are bundled with brokerage, information, or administration assistance as necessary to help clients realize their water management objectives. All proceeds are reinvested in fulfilling the DRC mission of improving water quantity and quality in Deschutes Basin streams.

CASE STUDY: CONSERVATION ACTIVITIES BY THE TUMALO IRRIGATION DISTRICT

The Tumalo Irrigation District (TID), which adjoins the Bend municipality, serves approximately 60 square miles with over 8,090 irrigated acres and 612 land owners (compared to 165 land owners in 1970 and 480 landowners in 1980). Higher density development creates difficulties in maintaining ditches and canals, raising questions of viability of irrigation operations. The District also faces challenges since few land owners are full time farmers, ownership turnover is high and some patrons may choose not to irrigate. The irrigation system now mainly serves pastures and hay operations for livestock.

TID is susceptible to water shortages due to the nature of its sources and relatively late priority date. Due to the geology of the region and the method of construction, unlined canals have huge transmission losses, estimated to be as high as 70 percent prior to the recent conservation activities.

Since 1995, TID has implemented an aggressive piping program of their primary canals. Initially, the TID proposed to pipe the entire system but the proposal was rejected by patron vote twice. Opposition views argued that the scenic value of the canals would be degraded and the District's water rights would be reduced. Consequently, the District has implemented a smaller, systematic, phased piping approach with significant monetary assistance from the US Department of Interior Bureau of Reclamation. Over the past nine years, the TID has piped 5.42 miles of main canal, including inverted siphons and flumes with diameters as large as 90 inches for a total cost of $10,430,500. The funding allocation has been approximately split 50/50 between the government and the TID which is an important factor in determining the instream flow component. The Oregon Watershed Enhancement Board and the DRC have contributed nearly 1.2 million dollars towards these piping efforts.

The District's second piping project installed 3000 feet of 60" concrete pipe along-side an existing 54" pipe in 1998. This brought capacity up to a total of 200 cfs at the diversion point, eliminating the need to use an alternative upstream diversion point. This saved the District about 40 cfs of water and its operation and maintenance costs. As a side benefit, it also restored flow in 9 miles of Tumalo Creek during the summer months when it would have been near dry. With continued efforts, fish passage from the Deschutes River into Tumalo Creek will be restored during the summer months.

In determining the amount of water to be put instream based on the Conserved Water Act, the State uses the lesser of two values. Either the maximum amount of water the water right holder can actually divert or the maximum water right, whichever is less. The new water right carries the same priority date and is subtracted from the lower of the two numbers described previously. The applicant can choose to make the new water right equal in priority date or one minute later. In TID's case, the District agreed to make the base instream water right superior to the District's water rights. This decision demonstrates the District's support for restoration work and confidence that it will not interfere with its ability to serve patrons. The minimum flow below the diversion will increase from zero to 5.8 cfs with the approval of the conserved water right certificate for all piping. The total conserved water flow will be as high as 17 cfs when there is flow available. Although this is a significant improvement to the flows of Tumalo Creek, the district still remains with a water right that allows them to divert up to approximately 200 cfs.

While the results of the piping project to date are saved water, the potential benefits to customers are much greater. Currently patrons operate sprinklers utilizing personally owned pumps. If the entire system is pressurized, customers will be able to operate their sprinklers without additional pumping, resulting in substantial energy cost savings. There is also the potential to generate hydropower within the system. Eliminating open canals reduces maintenance costs and liability for accidents. On the other side, patrons have argued in favor of canals for their esthetic value. Other irrigation districts in Central Oregon are faced with similar opposition to conservation projects.

CONCLUSIONS

Pro-active efforts of motivated organizations, agencies and citizens in the Deschutes Basin are resulting in reallocation of the limited water resource to meet changing demands while respecting existing water rights. Water leasing, mitigation and conservation programs are just some of the activities resulting in increased summer flows. Other programs are identifying and attempting to protect critical riparian habitat to prepare for the re-introduction of anadromous fish species to their historical range.

Factors that have contributed to progress in the Basin include the foresight of individuals who have spearheaded collaborative actions, a legal framework that enables effective water reallocation and the participation of stakeholders who contribute to a common vision. The lack of any single dominant agency in the management and regulation of water in the Basin and the relatively "backseat" role of the Federal government has allowed creative, cooperative efforts to succeed. A lesson learned from events in the Klamath Basin is that communities need to develop ways to balance environmental interests, municipal growth and irrigation needs before changes are forced upon them.

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THE ROLE OF WATER LAW AND WATER RIGHTS IN HANDLING INCREASING URBANIZATION IN THE WESTERN UNITED STATES

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ABSTRACT

In the Western States, the influences of drought, urbanization, and the environment are having dramatic impacts on water allocation and management. Some of the current trends include transferring agricultural water to municipalities, reusing treated sewer effluent, moving surface water rights to wells, promoting irrigation efficiency projects, and using water for environmental needs. These trends will change the timing, location, and quantities of diverted waters and significantly alter historic return flows from water use. As water communities transform, it is essential that water users understand these dominant trends and their associated impacts to water rights.

INTRODUCTION

There is an old rural legend which says, "Here in the wild west you can steal a man's wife or even his horse without getting shot. But if you steal his water, it's going to get ugly." And so it goes with water rights in the west. Utah is the second driest state in the union. Water is critical to surviving, and even more essential for thriving.

Need to understand the water right community in which we live

As most of the Western United States faces its sixth year of drought, the limited nature of our water resources has become crystal clear. This realization has greatly increased the awareness of the value of water and the importance of managing water rights. Within the last few years, we have seen a remarkable increase of activity in the water right community. This increase has been in both the number and scope of appropriation, change, non-use, and exchanges applications. An example of this can be seen in the letters of concern or protest written by the Bureau of Reclamation. In an effort to protect its water rights and supplies, the Bureau of Reclamation monitors the water right activities near its projects. In the year 2000, Reclamation sent out about 150 letters. In comparison, Reclamation has sent out roughly that same number of letters during the first 6 months of 2004.

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With this marked increase in water right activities, it has become essential for water users to understand the water laws and water use trends in their area. As individuals become informed about these laws and trends, they are better able to protect their rights and make sound water right decisions. As the public gains this awareness, they will be able to promote better water management. The purpose of this paper is to present a general understanding of water right trends and how they occur within western water law. Although our experience and examples come mainly from Utah, the general water trends and water law structures are similar in most western states.

TREND – AGRICULTURAL TO MUNICIPAL WATER CONVERSION

Currently the predominant trend in water use is the conversion of agricultural water to municipal and industrial water. In the late 1800's and early 1900's, when most states were establishing their water laws, the west was being settled and family farms dotted the land. These farmers and their community irrigation systems established the early water rights. Today, much of the west still consists of irrigated lands and many of these early water rights remain unchanged. However, an increasing amount of that farm land is now growing "kids" instead of crops, and with financial incentives strong towards urban development there is little doubt of this trend continuing.

Return Flows

It is interesting to note that the water demands of agriculture and subdivisions per acre of land are roughly the same. However, even with similar water demands, the return flows from each use can vary dramatically in quantity, nature, timing, and usability. This return flow issue will become increasingly important in the near future as more lands are developed. Traditionally, about half of the water applied to irrigated fields infiltrates back into the groundwater and/or returns to streams. Generally, this return flow takes place gradually over a couple of months and helps stabilize the late summer river flows. This can clearly be seen on the Provo River. As irrigation increased in Wasatch County (higher on the Provo River) in the early 1900's, flows in the lower Provo River in Utah County became more stable in the late summer months.

In contrast, much of the urban return flows occur through the sewer system. First, these return flows are reintroduced to the hydrologic system within hours to days of when the water was diverted. Secondly, these return flows are concentrated to a single point. Lastly, sewer treatment plants are typically located as low as possible in the hydrologic system. Therefore, the return flows may be reintroduced into the environment below the point where they can be beneficially used. This bypass effect can dramatically impact how many times the water can be reused in a hydrologic system before it travels out of reach of the uses. This bypassed water can easily skip by many farmers' fields and limit the beneficial reuse of the water.

Water Usage Patterns

Another impact of urbanization is the change in water demand cycles. Irrigation typically uses water during the irrigation season (April through October), with the greatest demand in the months of July and August. Afterwards, the irrigation ceases and there is no demand during the winter months. Conversely, cities use water year round. Although their demand increases in the summer due to irrigation of lawns and gardens, their overall water demand remains much more constant. One question that will need to be addressed is how a reservoir designed to provide water for irrigation will be impacted as both the return flows and water demands change with urbanization.

Municipal Water Shortages

One key difference between agricultural and municipal water use is how water shortages are handled. Traditionally, when water supplies have been low, as they are now, farmers adjusted to less than a full supply of water. Often fields are temporarily taken out of production or the irrigation season is shortened. However, water shortages are more difficult to handle after the water is transferred to municipal use. It is one thing to fallow a field and quite another to dry up lawns, gardens, parks and people. In the past, farmers have had to bear the lion's share of water shortages. However, as municipal water rights represent a greater portion of the total available water, farmers will no long be able to make up the shortages.

TREND - SURFACE WATER TO GROUNDWATER

One significant trend, in conjunction with urbanization, is the transfer of surface water rights to underground wells. As water rights are transferred to urban use, they need to be incorporated into city water systems. Since it is usually not feasible to build facilities to transfer and treat water from historic surface sources, this water is often moved to underground city wells. Additionally, since cities need a constant year-round supply of water and have difficulties handling shortages, a groundwater well fits their needs much better than a variable flow surface stream. This is particularly true on small drainages where streamflows can vary dramatically or dry up in drought years. On a similar note, we have also seen agricultural water rights transferred to groundwater for similar reasons.

Impacts

We are concerned with the cumulative impacts of these change applications for many reasons. From a basin-wide view, groundwater and surface diversions are drawing essentially the same water. In Utah, many aspects of underground water rights are treated the same as surface water rights. However, whereas surface water rights are limited to available streamflows, underground water rights have traditionally enjoyed a full supply of water even in the driest years. Therefore, these transfers tend to increase the quantity of water drawn from the basin and can lead to groundwater depletion.

Another concern with surface water to groundwater transfers is what happens with the abandoned surface water. As water is transferred underground, there is more surface water available. However since surface sources are already over-appropriated, especially in dry years, the entire streamflow will continue to be used. Therefore, this transferred water end up serving as essentially new appropriations in already fully appropriated basins.

Solutions

One solution to the disparity between groundwater and surface water is to manage the two resources conjunctively. One ground water management tool recently seen in Utah is requiring the water user to install water meters on both the abandoned surface source and the new well. The water quantity from the new well is then limited to the water that is available from the surface source. The State Engineer has further specified conditions to ensure that the abandoned surface water is not improperly used. Another management tool being considered in Utah is the limiting of groundwater withdrawals in areas where the groundwater table is declining. According to Utah water law, the junior water rights must be cut off to keep senior water rights whole. However, this is difficult to implement when it translates into putting farms out of business and depriving domestic water wells. In some cases, the State Engineer can use public pressures to encourage all the water users to share shortages to prevent cutting off any water rights. As urbanization continues, especially in these dry years, this issue is receiving much more attention.

CHALLENGES OF A CLOSED BASIN

In Utah, it is interesting to note that almost all urbanization occurs in areas that are fully appropriated in both surface water and groundwater. It would be convenient if all new development could be limited to the remote areas of northeast Utah where there is still some water left to be appropriated. However, since it may be difficult to find a politician to support this zoning practice, we need to deal with the challenges of a fully appropriated basin.

Over Appropriation

Over appropriation challenges are particularly intense in Utah and Salt Lake counties, where the water right appropriations over the past one hundred years now greatly exceed the available water supply. The saving grace has been that many of the appropriated water rights have not been fully used. In these over-appropriated basins, most cities require developers to bring in the water rights for their new developments. Usually the developer is required to acquire a water right and then submit the change application to transfer the right to a city water source. These change applications are cleanest when they come from the irrigation historically applied to the land being developed. However, this is seldom the case and often the developer is compelled to find water in another part of the basin.

Forfeiture

It is not surprising that the easiest water rights to acquire for development are those that are not being fully utilized. Water rights have been transferred from, obviously, abandoned wells with rusted out pipes, from once irrigated field that have been growing homes for the last 30 years, and from factories whose last building collapsed decades ago. Like most western states, where water is scarce, an emphasis has always been placed on ensuring that this resource is fully used for the most valuable purposes. To prevent water waste, most of the western states include a "use it or lose it" policy. Until recently, the common interpretation of the forfeiture clause in Utah was that only a significant portion of the water right needed to be used within a 5 year period to maintain the right's validity. This interpretation made it difficult to show nonuse, resulting in almost no water rights being forfeited in the state of Utah.

In 2002, the Utah legislature redefined the forfeiture statue. The new definition says that unless a "substantial" portion of the water rights is used during a 5-year period, then the unused portion may be forfeited. Although we are still waiting to see how this new definition stands in court, this redefinition has already had an impact on the Utah water rights community.

One result of this definition is that irrigation companies are now vulnerable to forfeiture claims. Many of the large water companies show much more land on their water rights than is actually irrigated. Many of these water rights were perfected in the late 1800's when most of the Utah and Salt Lake valleys were occupied by family farms. Because these irrigation companies have always used a significant portion of their water rights, they have not been subject to forfeiture. With the forfeiture redefinition, these irrigation companies now stand to lose tens of thousands of acre-feet per year. This new vulnerability appears to have motivated these companies to segregate and sell off portions of their water rights.

Litigation

Given the over-appropriated nature of the Utah basins, the resurrection of water rights will likely create significant conflicts with other water users. In many cases, the Utah State Engineer will act as the intermediary in these conflicts. The State Engineer carefully reviews water right change applications and if approved, imposes conditions to help mitigate the impacts of these changes. The State Engineer can even deny a change application if he feels the impacts will be too great or if he feels the water right should be forfeited.

However, even though the Utah State Engineer he can grant new water rights, he does not have the power to forfeit a water right. Forfeiture action are handled through the courts by another water user who can demonstrate damages to its interests caused by the use of the forfeited water. The water user that brings the forfeiture case to the courts does not necessarily receive the forfeited water when it reverts to the public. Therefore the forfeiture action provides only indirect benefits in many instances. In the past this has been sufficient to discourage private parties from filing forfeiture actions.

As water supplies become tighter, more and more water users will receive less than their accustomed full supply every year. Under these conditions an increased interest bringing litigation to enforce forfeiture of unused water rights can be expected. Because the benefits from a forfeiture action are indirect, many impacted parties may combine in a "class action" forfeiture action. Under the class action scenario, the shared litigation costs would be more proportionate with the benefits. In this scenario, many more claims could be brought forward.

WATER CONSERVATION TRENDS AND IMPACTS

Water conservation has become the "buzz word" of water management politics. Ask any politician the solution to water shortages, and conservation will most likely be the first response. Without a doubt, water conservation will become an increasingly important aspect of western water management. Common sense would dictate need to conserve water when supplies are short. However, water conservation will have a mixed impact on the water rights community, with those most impacted receiving little if any compensation.

Sewer Reuse

Sewer reuse has become a hot topic in Utah. In 1995, the Utah Legislature passed a statute that allows cities to reuse their sewer effluent, subject to certain limitations. Unlike other water right issues, the Utah legislature essentially provided a default right for cities to reuse their sewage effluent. Even though cities must submit a sewer reuse application, this application has essentially a pre-approved status. The State Engineer's only role in reviewing sewer reuse applications is to establish that it is consistent with the new Utah Statute. In the past, there has even been some question whether sewer reuse applications should be publicly advertised or not.

As with many conservation issues, there is no doubt that sewer effluent reuse will help extend the cities' water supplies. The dilemma is that this effluent has historically entered the natural water ways and become part of downstream water rights. Historically it has been assumed that indoor water use was only 20 percent consumptive with the remaining 80 percent flowing through the sewer treatment plant. However, the current standard in evaluating sewer reuse applications is to assume that any water right that was originally filed for municipal purposes is fully consumptive. If the cities start reusing their sewer flows, it stands to reason that water depletion will increase.

The question is not whether sewer reuse will happen, but how downstream water users will be made whole from sewer reuse. Looking to Utah water law, if the State Engineer treated sewer reuse like other change applications, he would have to limit the depletion of the municipal water rights to their historic values. Cities could apply for sewer reuse on the irrigation water rights they acquire through development. Because irrigation water rights are typically 50 to 60 percent consumptive, when used in municipalities there is a portion of the historic depletion that remains unused. This unused depletion could safely be reused without impacting downstream water uses. Additionally, cities often buy water that has been imported into the basin. Because the return flows of the imported water have never been part of the basin's water supply, they can be depleted 100 percent with limited impacts to downstream water users.

Another possible solution to make sewer reuse more palatable to downstream water users is to develop mitigation plans. This mitigation plan could take the form of buying irrigation shares and letting them flow downstream or paying farmers to fallow their fields when surface water supplies were low. The costs for these mitigation plans may be very reasonable considering that sewer treatment plants are located relatively low in the hydrologic basin with limited downstream users and that the cities need only to mitigate when there are water shortages.

Irrigation Efficiency

Irrigation efficiency projects fall under a category very similar to sewer reuse. Like sewer reuse, it makes sense to use irrigation water as efficiently as possible. However, like in sewer reuse, irrigation efficiency projects modify the historic return flows and can impact downstream water users.

Some examples of irrigation efficiency projects that have been common here in Utah include canal lining, enclosing and piping canals and ditches, and the conversion from flood to sprinkler systems. All of these irrigation efficiency projects behave very similarly from a water rights standpoint. The historic depletion of irrigation water rights is tied directly to the type of crop and the number of acres irrigated. Therefore, if crops and the acreages remain fairly constant, then there is limited impact to downstream water users from increased irrigation efficiency.

The water right issue with irrigation efficiency is what to do with the conserved water. In the past, this saved water has infiltrated into groundwater and has flowed to downstream water users. Therefore, historically the wasted water has had no depletion associated with it. From a Utah water law standpoint, the conserved water therefore can only be put to non-consumptive uses. However, it is difficult to get irrigators excited about paying for irrigation efficiency projects if they don't directly benefit from the saved water.

ENVIRONMENTAL NEEDS

One last factor that will play an increasingly important role in both water conservation and urbanization of water rights is the needs of the environment. As additional studies are conducted and more data become available, we are better able to assess the impacts of water use on the environment. This increased knowledge, coupled with the general environmental awareness of the public, will give the environmental water needs greater stature than ever before. Trying to meet the needs of agriculture, urbanization, and the environment will present some of the greatest challenges in the upcoming decades.

CONCLUSION

The key to an orderly and equitable transition can be found within the existing framework of the western water law. These laws have a dual nature; on one side they promote the water changes that result in the most beneficial use of water. The fundamental creed of western water law is "Beneficial use shall be the basis, the measure and limit of all rights to use water...." On the other side, western water law establishes rules and procedures that allow for equitable resolution of conflicts. For example, the laws dictate that the oldest water rights have highest priority, that all water right applications need to demonstrate no impact to adjacent water users, and that the public shall have a medium to voice their opinions and concerns.

Need for an Informed Public

A key to having an orderly transition of water rights is to have active public involvement. The public needs to be aware of how the state-owned water resources are being utilized. Allowing adjacent water right holders to have a voice in this transformation will reduce tensions and expensive litigations and allow for compromises. As we enter the information age, we can expect technology to play an important role in the public review process. Some possibilities includes: mass email water notices (sending an email to everyone within X miles of a proposed water right action), email protest letters, and a greater reliance of online water right databases. It is through this public involvement that the state engineer can become aware of the local concerns and make more informed decisions.

As the Western United States and other areas continue to urbanize, water law and water rights will play a large role in the orderly transition of water from historically agricultural purposes to municipal and other uses. The consequences of this transition are not clear-cut nor are conflicts easy to resolve. The challenge is to allow change to take place without allowing change to take place – in other words, permitting people and organizations to apply their water to their greatest needs without infringing upon other's rights in putting water to their highest and best use.

TOWARDS BALANCED SUCCESS — FINNISH EXPERIENCE IN WATER RIGHTS REGULATION AND WATER SERVICES

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ABSTRACT

Finland is extremely rich in water resources. According to the Water Poverty Index, Finland is the highest-ranking country in the list of the world's water-richest nations. Only 2.2% of the water available in Finland is actually used each year. The ownership of water areas in Finland is largely in private hands, which in practice means it is based on shareholdings. Any actions or physical structures affecting water bodies or groundwater resources are usually subject to permit. Individual permit consideration based on an application process has proven a workable approach in the Finnish conditions. From the perspective of guaranteeing water supply services and the costs involved, it is important that the owner of waters does not have the right to prevent others from abstracting water or applying for a legal permit to use the water. The owner is not entitled to a compensation for water on the basis of the amount of water taken. Water supply and sewerage are seen rather as services of general interest, which is why the availability of water services at reasonable cost is guaranteed by law.

STARTING POINTS

Finland constituted the easternmost part of the Kingdom of Sweden (Sweden-Finland) from early medieval times to 1809, after that it was an autonomous Grand Duchy under the Russian Czar from 1809 to 1917, and a sovereign republic from 1917. Finland has been a member state of the European Union since 1995.

Finland has about 60,000 lakes of various sizes and shapes, 200,000 km of shoreline of inland water bodies and the Baltic Sea, and complex water systems made up of subsequent ponds, brooks, lakes and rivers. Most of the groundwater aquifers are situated in gravel and sand eskers. Finland has abundant water resources. Recently researchers from the United Kingdom's Centre for Ecology &

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Hydrology and experts from the World Water Council using the Water Poverty Index[4] found Finland to be highest-ranking country in their list of the world's water-rich nations. Only 2.2% of the country's total renewable water resources are actually used each year. Water is taken mainly to meet the needs of industry and public water supply. Because of Finland's northern location and its climatic conditions, the amount of water needed for irrigation is very small.

Like land areas, inland and sea water areas are for the most part in private ownership, originally according to the principles of the old Swedish-Finnish legislation. These include the so-called middle line and shore shoal principles, as applied according to domestic rules after the separation from Sweden. Land borders between rural villages were permanently confirmed as a side-product of the fundamental village-level procedures of parcelling out land (mainly in the18th and 19th centuries). This made it possible to confirm the borders between villages in water areas as well, although this was not possible in practice until the legislation of 1902.

In spite of the predominant private ownership, there are also state-owned water areas, which mainly consist of the outer parts of Finnish territorial waters in the Baltic Sea and the middle parts of a few largest inland lakes. In addition, water areas within or, according to the middle line principle, adjacent to state forests belong to the state. The state forests are mainly located in remote northern and northeastern regions.

In practice, the private ownership of water areas means joint ownership at village level. The parcelling out of land normally left a village's water areas to the landowners of the village jointly, and a specific parcelling out of waters later on has been quite difficult. This means that water areas are mainly owned jointly by the shareholders of a registered village's common areas. The shareholders form a statutory shareholders' association, which plays an important role especially in the management of fishery rights. The shares, initially belonging to the former farms according to fixed ratios based on their relative original land value, are transferable, but in connection with land purchase according to quite sophisticated rules on transfer or non-transfer and on the exact amount of the share, they are controlled by registered surveying. The system of common areas and shares to them is the main reason for the extraordinary complexity of the Finnish land registry system, with almost three million entities.

Although the ownership of water areas and their areal distribution is crucial, for example, in disposing hydroelectric power or fishery rights, its importance should not be overestimated. In respect of the real disposal of areas, the ownership is far less decisive for waters than for land. There are many reasons for this. Firstly, extensive rights of public access and common use apply in water areas. These

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[4] World Water Council & UK's Centre for Ecology and Hydrology, 2002

include boating, water traffic and timber floating, and fishing, mainly as recreational activity. The ownership of water areas does not include the ownership of the water itself, which is considered to be at the disposal of the owner of the water area on a temporary basis only. The shore land owner also has a right to small-scale water intake independent of the ownership of water areas.

Secondly, the water legislation is traditionally based on a permit system where the owner or shareholder is not necessarily in a more favourable position than an outsider applicant, and other interested parties are also strongly involved. The permit procedure is more like a system for case-by-case setting of norms and a framework for the participation by interested parties than an administrative mechanism for command and control. Orders concerning compensation (by the applicant) for future damage are, whenever feasible, ex officio included in the permit decisions. And thirdly, various expropriation-type powers may be included in a permit decision, which may allow an outsider to get a permit, for example, when a project is considered necessary for general interest. The state or municipal authorities also need a permit according to the same rules as a private party.

THE PERMIT SYSTEM

The Water Act (1961) is the most extensive parliamentary act of Finland, measured by amount of text. This illustrates the variety of the different activities and legal phenomena covered by the Act, and its nature as a jointly substantive (in relation to both public and private law), administrative and judicial enactment. However, the length of the text does not necessarily imply detailed provisions. Many key provisions are instead based on general clauses and notions, which stresses the role of case-by-case decision by independent permit bodies. Any actions or physical structures affecting water bodies or groundwater resources are usually subject to permit. These permits reconcile the various use requirements and conservation issues in each individual case, taking the due process of law into account. Individual permit consideration based on an application process has proven a workable approach in the Finnish conditions.

According to the Water Act, since 2000 the permit bodies are the three Environmental Permit Boards, which replaced the previous Water Courts. The appellate courts are the Vaasa Regional Administrative Court, and ultimately the Supreme Administrative Court. The Environmental Permit Boards are independent and consist of experts on law, engineering and environmental sciences. The Boards have comprehensive competence in permit and injunction matters set down in the Water Act, and a rather large competence also according to the Environmental Protection Act of 2000. According to the latter, also Regional Environment Centres and municipal environmental boards are vested with permit powers, according to detailed competence rules, dealing with less important permits than the Environmental Permit Boards.

The discretion by the Boards is judicial, which means that all political and governmental influences not based on the law are excluded. A permit must be granted (with all necessary provisions included), if no obstacles exist, and a permit must be refused, if any relevant obstacle (which cannot be removed by using the permit provisions) exists. This may, however, be a matter of legal interpretation. The permitting – in fact, protection of a wide scope of private and public interests – is pronouncedly on a case-by-case basis but, on the other hand, the decisions are under the appellate control by the administrative courts, whose role is important in both procedural and substantive issues. The permit procedures are frameworks for participation by impacted parties and associations, and many damages to third parties are also decided upon ex officio. According to the Water Act, elements of compulsory purchase, where necessary for the project, may be included as well.

WATER SUPPLY AND THE WATER ACT

From the perspective of guaranteeing water supply services and from the cost aspect, it is important that the owner of water or land areas does not have the right to prevent others from abstracting water or applying for a legal permit to use the water. The owner is not entitled to a compensation for water on the basis of the amount of water taken. Thus an owner of water or land areas over groundwater bodies does not have a protected right to unchanging quality and quantity. On the other hand, the owner does have a right to compensation for any damage caused by the abstraction of water.

In all permit matters under the Water Act, not only the issue of permits but also the question of due compensation to third parties must be examined ex officio. This simultaneity principle means that third parties suffering damages from a planned project as well as parties who are obliged to convey rights to the applicant will get their compensation without delay as part of the same procedure. If the damage cannot be foreseen at the time of the permit application procedure, it is possible to raise a compensation procedure separately.

The Water Act contains provisions on reconciling competing needs for water supply in situations where there is not enough water for all who need it. In this case, priority is given to 'neighbourly use', i.e. use by homes and farms in the immediate vicinity of the point of supply. Next in order of priority is use for the needs of the public water supply. This principle will be defined in greater detail in the context of the current revision of the Water Act so that future needs will be taken into account more explicitly.

PUBLIC WATER SERVICES

The organization of public water services is provided for in the Water Services Act, which came into force in 2001. The Act contains provisions on the responsibilities of municipalities, utilities and real estates, and it harmonises the regulation of payment systems between the water utilities and their customers. In the Water Services Act, water supply and sewerage are seen more as services of general interest than as municipal engineering. This view is becoming predominant in Finland as well as in the other EU countries. Because the general interest is involved, the availability of water services at reasonable cost is guaranteed by law. The purpose of this is to secure everyone the access to healthy, high-quality household water as well as appropriate sewerage and purification of wastewater in terms of health and environmental quality.

Most water utilities are owned and operated by cities and municipalities. However, the independence of the utilities has grown and today also publicly owned companies have been established. Some utilities in rural areas are operated by water co-operatives owned by consumers. There are also various forms of inter-municipal co-operation in water services.

Water and wastewater charges for water services are based on water consumption, but there are also certain fixed fees, such as the connecting, basic and metering charges. The average price of water is about 1,3 €/m^3, when increments caused by metering, fixed fees, etc. are included. The average wastewater charge is about 1,7 €/m^3.

Government subsidies represent close to 10 % of the total yearly investments in water services, which comes to about 250 million € / year. Subsidies are still needed for improving the preparedness for emergency situations, enhancing regional co-operation and occasionally improving water supply and wastewater treatment in sparsely populated rural areas. No government subsidies are available for the operation and maintenance costs.

AGRICULTURAL WATER MANAGEMENT

Despite the very unfavourable climate, self-sufficient agriculture and keeping all parts of the country populated have always been the Finnish tradition. Since the accession to the EU, agricultural output has been close to the self-sufficiency level. Current development prospects suggest that it should be possible to continue agricultural production at about same level in the future, too. The current GPD share of agriculture is 1.2 per cent.

The role of irrigation is relatively insignificant in Finland, and in practice it is mainly used in the cultivation of vegetables. According to the water legislation, farms can, even without permission, take irrigation water for their own use from natural waters. In some situations it is also possible to use small amounts of water provided by water utilities.

The government does not construct or maintain irrigation systems in Finland. Contrary to this, flood control structures and major drainage systems have been financed partly by the government. Farms invest in irrigation systems themselves. However, the acquisition of irrigation systems can be subsidised, subject to certain requirements, by the EU investment support and environmental support. The willingness of farms to invest in irrigation has been decreasing as agricultural support is paid on the basis of the area under cultivation instead of the yield produced, as was done before Finland joined the EU.

Today the average farm size in Finland is about 30 hectares. Milk production is still the most important agricultural sector. Farm size is growing mainly because the least productive farms are giving up production. In the beginning of the 1960s the number of farms was at its height, almost 300,000. Since then it has been falling rapidly, especially after joining EU, and it is expected to reach a level of 60,000 in 2005. This implies growing challenges to the water supply and wastewater treatment systems of e.g. dairy farms. In the future the majority of farms should be connected to municipal water supply and sewer networks.

LATEST LEGISLATIVE DEVELOPMENT

The bulk of the environmental legislation of the EU was implemented in 1994. The amendments to the Water Act mainly concerned the provisions on the prevention of pollution. This caused no major changes or practical effects. The existing law already required a permit for various discharges more extensively than was required by the relevant EU Directives. Neither was there any change in the substantive requirements, with the exception of the necessity to remove nitrates, in addition to phosphates, from municipal effluents in certain cases. In general, the various, largely obsolete technical requirements of the directives only became a formal checklist for the permit authority. The Directives on EIA and on the protection of nature have also influenced the Water Act.

At present, the greatest impact of the EU law results from the new Water Framework Directive (WFD) of 2000. The aim of the Directive is to achieve a good ecological status of water by 2015. The WFD requires an economic analysis to be completed by the end of 2004. It constitutes an important contribution to increased integration of economic considerations into water management. One important part of the analysis is assessing the current level of cost-recovery of water services. In Finland all the water utilities using more than 500 m^3 of water per day – nearly 300 water utilities – are investigated. Earlier studies have revealed that around 20% of the total amount of water distributed is priced so that the owners of the utilities get higher than moderate profit. These utilities are owned by the largest towns in Finland. On the other hand, there are also a large number of utilities of small municipalities receiving constant support.

FUTURE PROSPECTS

The development and implementation of the common agricultural policy of the EU as well as EU water policy are key issues in the future. Agriculture must be environmentally friendly, taking environmental considerations and protection into account in all it does. The EU and national agricultural policy will change from subsidising the product to subsidising the producer. In the future more support will be focused to environmental, especially water protection purposes.

Although the management of water resources is based on the principle of social, economic and ecological sustainability, there is a need to further enhance the transparency and interaction in water issues. The EU Water Framework Directive brings new challenges to the entire sector, including revision of national water legislation.

Recently there has been a certain amount of public debate on the abstraction of water for commercial purposes. The public opinion has been controversial especially in cases where the abstraction of water would bring about a transfer of large amounts of water to other parts of the country or overseas. The Water Act is based on the premise that unnecessary limits are not set for taking water for commercial purposes, provided that other water supply needs, especially those of domestic and municipal drinking water supply, are met. However, commercial water abstraction, as well as water transfer generally, will be the last in the order of priority.

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IRRIGATION MANAGEMENT IN AFGHANISTAN: THE TRADITION OF MIRABS

Eric Viala[1]

ABSTRACT

Like in other Central-Asian and Middle-eastern countries, Afghan farmers have over the ages learned to cope with a limited and infrequent supply of water and have developed appropriate structures and mechanisms. Afghanistan can boast of a very robust tradition of water user associations organized around canals and mirabs: operation and maintenance of traditional irrigation systems are carried out by local water users, typically headed by a *mirab,* ie a watermaster, not unlike the mayordomo of the aceqias of Mexico, the canalero of northern Latin America, or the amazil of Morroco (aiguadier in France). Each of these roles has his own specificities and the Afghan model is adapted to the Afghan natural and social background. This model worth studying as it is ages-old, and managed to survive the past 23 years of chaos. The mirab in Afghanistan is usually a respected elder that acts altogether as a steward of the water conveying infrastructure, a controller of water flows and a facilitator of allocation disputes.

INTRODUCTION

The Afghan economy, like other Central Asian economies, still heavily relies on agriculture. The aridity of the climate causes water resources to be scarce, and 80% of agriculture occurs through irrigation. Like in other Central-Asian and Middle-eastern countries, farmers have over the ages learnt to cope with a limited and infrequent supply of water and have developed appropriate structures and mechanisms. We will here shortly introduce the structures involved but mostly elaborate on the societal organization for water allocation with the leading role of the mirab (traditional watermaster).

HISTORICAL CONTEXT

Despite its aridity Afghanistan has a long history of agriculture and settlements boasting some of the oldest known sites of irrigation in the world. Since its early development in Mesopotamia around 7,000 BC, irrigation spread gradually from the Middle-East through Central Asia and up to China. By 2,000 BC large tracts of land were irrigated in Afghanistan. As irrigation networks expanded, methods to control and manage them developed and it is widely acknowledged that this

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was the engine behind the early forms of civilizations: the administration of scarce water resources being central to the social and political hierarchy [Wittfogel]. Water was viewed as a "Gift from God" which could not be owned or controlled by an individual, but had to be used for the welfare of the community. Because of the importance of water to grow food, those responsible making decisions regarding water allocation and distribution were usually among the community leaders or important administrative officers.

One of the first detailed descriptions of traditional water management strategies is the Mujam ul-Buldan, Yakut's large geography written in the early 13th century. Yakut provided an excellent insight as to how water was managed at Merv (in present Turkmenistan), which at its zenith in the 11th-13th centuries was one of the largest cities of the Medieval world. The Mirab determined the amount of land to be cultivated in the oasis each year based on the level of the river in spring. Moreover, hourly reports on the level of water in the main canal were passed to his office to enable decisions on which off-takes were to be opened and closed. The system was so large that over 12,000 people were employed to maintain and manage the system. Moreover, all water users were obligated to take part in communal maintenance as well as pay for the water they used.

IRRIGATION IN AFGHANISTAN

The topography of Afghanistan is characterized by extensive desert plains, high mountainous ranges and scattered fertile valleys along major rivers. Roughly half of Afghanistan is located at an altitude of over 2000 m. Afghanistan has a dry continental climate: ninety percent of the country's limited annual precipitation (300 mm on average) occurs during the winter months between December and April, mostly falling as snow. In general, rainfed agriculture is subject to chance and consequently of limited productivity, while river flows allow spring and summer irrigation with greater agricultural output in the plains.

Agriculture is estimated to produce 85 to 90% of Afghanistan's Gross Domestic Product, and employs 70 to 80% of the population. It is the principal source of livelihood for a large sector of the rural population, particularly those living in more isolated regions of the country. Those provinces with the largest irrigated areas include Kandahar and Helmand in the south, Herat in the west, Baghlan, Balkh, and Kunduz in the north and Ghazni in the southeast. These seven provinces have the largest areas of low elevation (flat land) on the periphery of the country, located along the valleys of the four major river basins of the country, the Helmand River and its tributaries in the South, the Hari Rud in the west, the Balkh and Kunduz Rivers in the North, and the Kabul River in the east.

There are five basic types of irrigation in Afghanistan. These include: (i) modern surface systems, (ii) traditional surface systems, (iii) springs, (iv) karezes, and (v) wells. Modern systems represent approximately 10% of the total irrigated area;

karezes (see below) traditionally have represented about 5%; springs represent slightly more than 5%, and traditional canal irrigation systems with intakes from various rivers and streams represent more than 80%.

Modern and traditional systems divert river spring/summer flows for surface irrigation. Modern irrigation systems are characterized by the presence of perennial concrete infrastructure and machinery-dug canals. These have usually been funded by international donor agencies during the second half of the twentieth century. They are larger than 10,000 hectares and can be as large as 100,000 hectares. About a dozen modern systems exist in Afghanistan with an aggregate command area of around 350,000 hectares.

Traditional schemes are those which have few or no engineered structures and which generally rely on earthen water conveyance and control structures for water delivery. Typically they have been constructed by the users themselves ages ago. Traditional systems can be quite large (thousand of hectares and more). Where traditional systems have been selectively improved, the two system types tend to blend seamlessly together. Traditional canal-based schemes are widely distributed in every province in the country. They range in size from a few hectares in high mountain valleys to extensive networks covering thousands of hectares. They occur most extensively in the larger lowland provinces mirroring the distribution of overall irrigation in the country.

The three other types of irrigation tap into groundwater resources. Karezes (similar to the Qanats in the Middle-East, or rhettaras in the Maghreb) are traditional underground tunnels dug to reach the aquifer table and convey water to the surface some distance down slope. Estimates of the total number of karezes in Afghanistan range from 7,000 to 8,000. They are concentrated almost exclusively on the eastern, southern, and western flanks of the Hindu Kush. The past 23 years of war and strife have been extremely hard on karezes, which require regular maintenance and intensive manual labor to work effectively. Drilled wells are rapidly replacing karezes as supplementing surface irrigation systems and some cases bring new land under irrigation. These are abundant, and noticeable adjacent to the road from Kandahar to Kabul. These wells have become a significant and growing source of irrigation water. At present, no data are available to document the number of these wells, or their contribution as a new source of irrigation water. The trend to deep wells needs to be watched very closely, and could represent a dramatic future policy challenge for the government because of its unsustainability.

OPERATION AND MAINTENANCE OF TRADITIONAL IRRIGATION SYSTEMS IN AFGHANISTAN

Operation and maintenance of traditional irrigation systems are carried out by local water users, typically headed by a *mirab*. The word "mirab" which is also used in Iran and in Central Asia, comes from a combination of the Arabic word mir (or amir-emir) which designates a leader, and ab, the dari word for water. The mirab is thus by definition the watermaster, not unlike the mayordomo of the aceqias of Mexico, the canalero of northern Latin America, or the amazil of Morroco (aiguadier in French). Each of these roles has his own specificities and the Afghan model is adapted to the Afghan natural and social background. This model worth studying as it is ages-old, and managed to survive the past 23 years of civil strife.

The mirab in Afghanistan is usually a respected elder that acts altogether as a steward of the water conveying infrastructure, a controller of water flows and as a facilitator of allocation disputes. We shall look at these various roles in turn.

As the steward of the infrastructure, the mirab spends a lot of his time walking along the canals, checking regularly upstream on the river intake (or mother well in the case of a kareze), on the main conveying canal, on the secondary canals, on the control structures such as weirs and turnouts. If maintenance works are needed, either because of ageing or because of disastrous events (generally floods), the mirab will require men from the communities served by the system to provide free labor. As an example, in the case of the intake of the canal being wiped out by a river flood, mirabs of larger canals are able to mobilize up to several hundreds farmers (bringing their own tools) who will work without being paid up to a few weeks under his and his assistants' supervision to rebuild the mud and log barrage. These workers, through the provision of free labor, informally renew their rights to get water. It is common practice for mirabs to keep track of who showed up or not, and those who repeatedly do not participate in canal repair and maintenance will be denied water.

As the controller of water flows, the mirab and his assistants personally operate or supervise the opening and closing of the various structures which distribute water from the main canal to the secondary and tertiary canals and then to the individual fields. Allocation of water is made based on different types of measurements:

- At the intake or along the main canals, flows are divided (between right and left banks, or different branch canals) through proportional weirs; likewise the width of turnouts corresponds to the share of that turnout and usually relates to the amount of land to be irrigated by that turnout;
- In time of drought, a more detailed timetable will be drawn by the mirab (after extensive consultations within the community) and water turns will be implemented

There are usually different levels of allocation processes: the head mirab (mirab-bashi) manages and allocates water along the primary canal, while along branch or secondary canals (each usually serving a village or a community), water resources are allocated by sub-mirabs or directly divided by the communities/villages served.

As the facilitators of water disputes, the mirabs regularly solve minor disagreement on the spot. This is usually achieved through consultations of all parties, the search for a consensus or lacking this use of the mirab's moral authority. Major quarrels are referred to the *Shura,* the village or community council (also called jirga in Pashtu). The dari word 'shura' comes from the Arabic 'mashwara' (to discuss). It describes the traditional advisory council formed to solve conflicts, or deliberate on decisions affecting the community. The core of such councils comprise those whose opinions, negotiating skills and knowledge of tribal and/or religious law are respected, usually including elders, religious authorities, and local leaders. Any male head of household can attend the shura and all parties attending the shura are allowed to speak but obviously all voices in the shura are far from equal. While the council itself may have no direct means of enforcement, its authority is respected, and those who do not comply with its decisions will find themselves at odds with the community.

The mirab is usually a respected elder within his community. Mirabs are formally chosen (co-opted) by the shura for a given period of time (one to several years). There is definitely an apprenticeship process that leads to the position: most if not all mirabs started as assistant mirabs (called "checkbachis") and only after serving in that position for a period of time, graduated to the higher position. Some mirabs actually "inherit" the position from their father after serving as an assistant.

The water management organization lead by the mirab seems to vary quite a bit: in some instance, there is one mirab (with some assistants) for the main canal, who controls the canal intake and the distribution into secondary canals. Longer canals can be operated by two (or maximum three) mirabs, one being the upstream mirab and the other being the downstream mirab. They confer for major decisions, but each of them maintains his part of the canal and operates the turnouts. As previously explained, secondary canals can be managed by sub-mirabs or directly by the communities.

Water users, beyond the provision of free labor for the maintenance of the infrastructure, pay the mirab and his assistants for his services. The price varies, but the average "salary" for a head mirab seems to be one "man" (about 5 kg) of wheat per jerib (about 0.19 ha). Most mirabs acknowledge that not all farmers pay, and that they tend to classify households per their wealth. The poorest households do not pay and are not held liable as long as they provide labor. While peer pressure and social constraints demand that rich households pay their dues regularly.

MIRABS AND MODERN IRRIGATION SYSTEMS

Starting in the early 1950s, Afghanistan launched itself in a program of irrigation development, partially funded by donor agencies. About a dozen large irrigation systems were built in the following twenty years, some of them including reservoir infrastructure. All these systems are larger than traditional ones and cover more than 10,000 ha. Their construction by the central authorities meant that parastatal agencies (Helmand Valley Authority, Nangrahar Valley Authority) were created to maintain and manage them. This top-down type of management was originally accepted in some systems such as Helmand (irrigating new lands) because of the lack of a pre-existing social structure and of technical skills: settlers came from different regions, and initially most were nomads. But either initially or after some years, the control of secondary and tertiary canals was taken over by farmers and mirabs appeared in all modern systems.

Governmental and parastatal agencies kept control of the intake and primary canal mainly because the size of the primary infrastructure required large maintenance equipment that only governmental agencies could pay for. Communities through their mirabs would manage and maintain secondary and tertiary canals. Drains were also mostly maintained by the agencies as farmers were mostly unaware of the need for drainage: all traditional systems are along rivers on fertile and well drained silty soils, while some of the modern systems were developed outside of the river valleys on more sandy and thus more salinization-prone soils. Such was the situation in Afghanistan until the late 1970s.

SOVIET INVASION AND CIVIL WAR IMPACTS ON THE MIRABS

The Bolshevik Revolution and the subsequent emergence of the Soviet Union initiated a period of radical change in Central Asian water management. Water and land were no longer owned by individuals or communities but were common resources to be developed for the benefit of the country. Early on, the Soviet administration decreed that water management was to be taken 'out of the hands of traditional elders and councils. There emerged instead a number of government bodies who were responsible for the development of a regional water management strategy plans that would allow centrally determined production targets to be met.

The Soviet occupation of Afghanistan (1979-1989) was too short and too unsteady to launch similar changes. Although there are instances where the mirabs were replaced by Party members, generally to the detriment of the operation and overall productivity of the irrigation system, this seems to be more an exception than the rule. In such cases of authoritarian designation of the mirab, it was done more as a way to to assert better control over the local community, but not as a larger governmental policy. Most mirabs actually kept their positions. The disruption of irrigation systems was mostly due to the destruction of infrastructure, the devastation of fields, and the displacement or exile of populations (often caught in the cross-fire between the Soviet Army and mujahedins).

The civil war that occurred thereafter (1989-2001) provided the same type of impacts: while few mirabs were authoritarily replaced, the same destruction of infrastructure and departure of farmers into exile occured. The Talibans, not unlike the Soviets, seemed also to have practiced a "scorched earth" tactic in the non-Pashtun regions (notably in the central Hazarajat and in the Tajik Shamali plains, just north of Kabul).

But during the entire period since 1979, the chaos and lawlessness contributed to undermining the role of mirabs, as communities were ripped apart: valuable irrigation structures were sometimes damaged because of long standing feuds between neighboring families, villages or tribes. But more importantly the collapse of social cohesion lead farmers to take water out of turns, or over irrigate their plots, to the detriment of downstream users. Warlords grabbed lands and water rights, building their own turnouts to divert water from the canal. This situation resulted in increased wastes of water while mirabs could only watch powerless, their moral authority no longer acknowledged.

THE SITUATION TODAY

Traditional systems have generally more or less survived these 20 years of turmoil, because the communities themselves have been able to preserve some type of cooperative management of water resources, and mirabs are still today selected and put in charge of supervising the irrigation processes. Some traditional systems suffered more because they happened to be located on battle frontlines, and their infrastructure was destroyed, forcing the majority of the community members into exile. The four-year drought recently (1998-2002) experienced all over Central Asia also heavily impacted Afghanistan and contributed to the exodus of farmers. However there are definitely encouraging signs of recovery in most traditional systems. From a rehabilitation perspective, assistance is definitely needed to bring back these systems on their feet, as returning farmers are usually in debt and thus have absolutely no resources besides their arms to resume farming. Caution should be exercised during rehabilitation assistance as there is a clear danger of further disrupting the social organization: paying workers to clean a canal while farmers are supposed to contribute free labor to do so can be considered for heavily silted up canals, not for yearly cleanup operations. Why would then farmers work for free if by complaining to donors, they can get paid for the same labor? This however would have major consequences on the way the community handles irrigations systems, since for example the provision of free labor is directly linked to the water rights of individuals.

Modern systems on the other hand suffered more because while governmental agencies lost operational capacities in terms of funds, staff and equipment, maintaining them proved beyond the potential of water users. Farmers almost completely took over the secondary and tertiary canals, while some technical staff stayed on (even if paid once in a while) and acted as informal advisors. An interesting example is the state farms in Jalalabad: the Nangrahar Valley Authority could not pay staff any more and ended up leasing public lands to farmers in order to carry on agricultural production, generate some income to pay for limited maintenance.

From a rehabilitation perspective, the focus should clearly be on modern systems, and in these on those structures that local farmers have not been able to maintain on their own, such as drains, intake, and primary canal.

CONCLUSION

Today the role of the mirabs is as crucial as ever, not only because of their activity but also because they represent the social cohesion of communities, along with other types of leaders or activities. The needs are multiple, from the construction of perennial infrastructure, technical training on water allocation and use efficiency, to the provision of equipment or rural credit. Extension services have to be developed to improve agricultural practices, and sensitization to equity issues should be introduced, looking at poorest segments of the population and most notably women. The underlying key question is how to strengthen the informal water user associations lead by mirabs without disrupting them.

Looking at modern systems, one can assume that secondary and tertiary infrastructure can and should be managed in the same way as traditional systems. The additional key issues are the maintenance and operation of the primary infrastructure, the partnership between the governmental agency in charge of this and the water users, and the funding of the works. The mirabs are the obvious link.

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INSTITUTIONAL REFORMS IN IRRIGATION SECTOR OF PAKISTAN: AN APPROACH TOWARDS INTEGRATED WATER RESOURCE MANAGEMENT

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ABSTRACT

Since 1995 the Government of Pakistan has been making efforts to restructuring the century old irrigation system by involving beneficiaries (water users) at various units of the irrigation system management. The main purposes of reforms are: to improve operation and maintenance (O&M) of irrigation system, to make balance in expenditure and revenue, to improve crop production through efficient use of water, maintain affordable drainage system and develop an integrated water resource management (IWRM) approach.

In these reforms, the Irrigation Department has been transferred to an autonomous body – Provincial Irrigation and Drainage Authority (PIDA). Under PIDA, Canal Area Water Board at each canal command area and Farmer Organizations at each secondary canal (Distributary/Minor) command area being formed. These all units are now responsible for irrigation, drainage and environment in their jurisdiction.

Because of culture, political influence, social and economic set up of Sindh Province of Pakistan; it was argued that the formation of Farmer Organizations would be hard and challenging part of institutional reforms in irrigation sector for any organization. But the International Water Management Institute (IWMI) successfully completed the experience of formation of Farmer Organizations on thirteen distributaries at the time of project. This experience has further resulted in continuous formation of FOs. Until now the formation of FO on one canal command area, having 163 distributaries have been completed.

As part of the program, the capacity building activities for members of the organizations being carried out through training and awareness which has subsequently proved that the FOs are holding regular meetings and discussing the issues relating to irrigation and drainage, organization set up, and resource mobilization.

The participation of farmer members and management committee members in all events organized at various time and purposes has proved successful as 70-75

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percent attendance was observed. For improving the physical system, all farmers contributed voluntarily in cash and kinds, which resulted in improved water distribution by 60 to 70 percent.

Paper concludes that the approach adopted for improving water conservation through giving the water rights to the end-users is one of the best tools. However, still it is at initial stage therefore, no concrete result could be made. Further paper gives the impression that without giving due consideration to basic unit organization that is farmer organization (or Bottom-up approach) the result oriented system performance would not be possible.

INTRODUCTION

Issue of distribution and access are also critical in understanding the role of water in rural livelihoods. In many cases, formal legal frameworks usually guarantee equitable distribution of water; however, in practice they are not enforced, and the powerful monopolize access. Further, some claims to water are based on informal or customary rights that may be more difficult to defend, especially in the face of social changes such as significant in/out- migration or increased market integration. Ensuring access to water quality is similarly problematic.

The developing countries have the challenges as: Increasing population; increasing demand for food and other crops; poverty and famine; human resources constraints: health, education, and training; women in development; natural climate constraints: land and water; market competition from industrial and other countries and global warming. These all are possible irrigated agriculture is given priority and integrated approaches are developed. [John Hennessy 1990].

The foremost factor is the expected population growth in developing countries. Under the most optimistic scenario, which assumes successful population programs, world population will grow from 6.2 billion in the year 2000 to at least 8 billion by the year 2025.This growth will increase the demand for food supplies and thus the demand for irrigated agriculture production necessary to produce sufficient food worldwide. This demand will in turn create serious water management challenges in countries where additional supplies of aerable land and water at reasonable costs are almost exhausted. These problems are especially serious in countries where water logging and salinity are causing a reduction in the irrigated area [Guy Le Moigne 1990].

To improve the sustainability of irrigated agriculture is the urgent need to review current practices and standards and formulate new criteria for various aspects of irrigation system design, and incorporating environmental safeguards. Further, the water logging and salinity control must be linked to sound irrigation water management, including water saving techniques and the proper maintenance of irrigation and drainage systems [Tom Brabben, etal 1991].

This water is used predominantly in agriculture to grow the food and fiber on which human society depends. In Pakistan, more than 70 percent of the rural populace depends on agriculture and mostly they irrigate their lands through one of the worlds largest and century old contiguous irrigation system. With the passage of time, this system has deteriorated and now facing with several problems. These are: less recovery of water charges, over expenditure on operation and maintenance, poor operation and maintenance, inequitable distribution of water and unreliable supply and rent seeking. To overcome these problems institutional reforms were identified and suggested for implementation in the system that will support to water conservation, food security, poverty alleviation and sustainable agriculture.

BACKGROUND

Since the mid 1990s, Pakistan has been seeking to reform its irrigation sector. The primary motivation behind this effort is to create financially sustainable irrigation agencies and improved operation and maintenance of the infrastructure and give the responsibility to end-users of their water rights so that the system should be self sufficient and sustainable.

The entry into force of the 1997 Provincial Irrigation and Drainage Authority Acts, paved the way for the creation of three new institutions. Irrigation Departments will become semiautonomous Provincial Irrigation and Drainage Authorities (PIDA). Area Water Boards will be formed, through which farmers and personnel of PIDAs will jointly manage irrigation and drainage networks at the canal command level. Management responsibilities at the distribution level will be transferred to Farmer Organizations (FOs).

Beginning in 1995, IWMI Pakistan ran three pilot projects at Bareji and Heran Distributaries and Dhoro Naro Minor in the Sindh Province of Pakistan, later in 1999 other ten distributaries were included in the pilot project. The objective of this work was to test the viability of FOs and their capacity to participate in the management of their irrigation and drainage systems at the local level. This study specifically focuses on the pilot projects in particular and institutional progress in general in the Sindh Province of Pakistan. The pilot area is shown in Figure 1 and salient features are shown in Table 1.

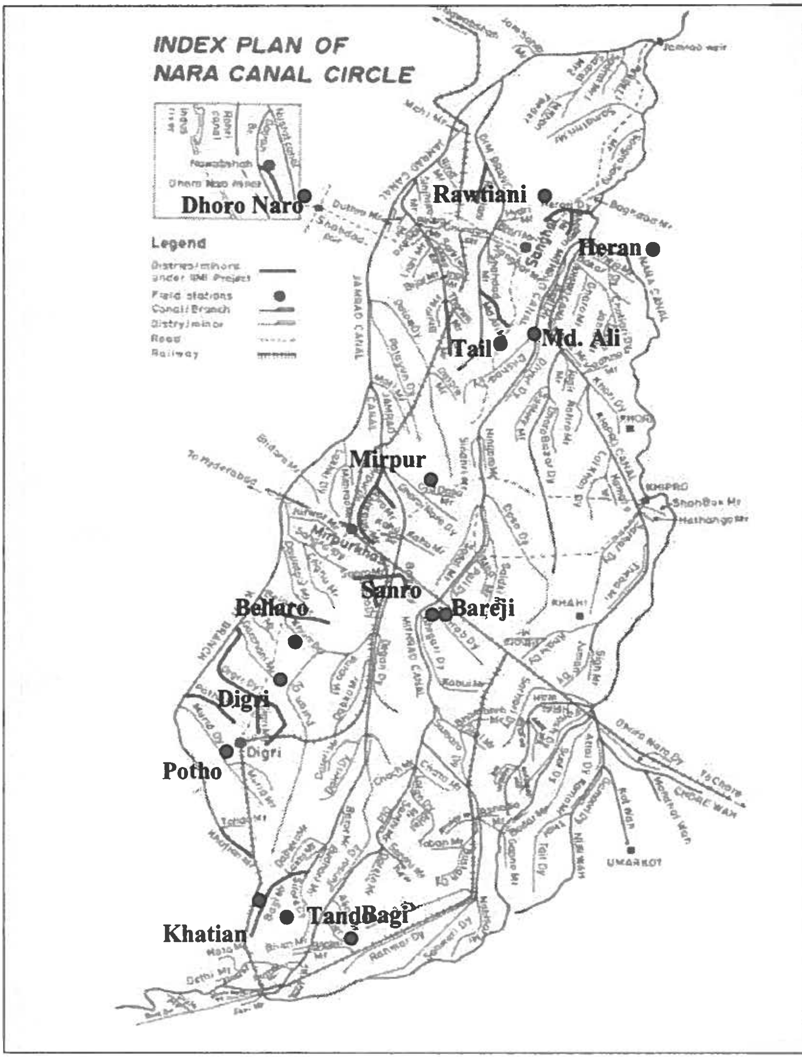

Figure 1. Location map of the pilot distributaries of IWMI projects

Table 1.Salient Features of the Pilot Distributaries

Distributary/ Minor	Command Area (ha)	Design Discharge (m3/sec)	Canal Length (m)	Number of Outlets	Canal Length/ha of command area (m/ha)
Heran	4994	1.77	9754	31	1.95
Rawtiani	3658	0.83	8382	19	2.29
Bareji	5797	1.18	11979	24	2.07
Mirpur	6566	1.74	14630	53	2.23
Potho	3264	0.82	10058	19	3.08
Dhoro Naro	5418	1.46	9836	25	1.82
Mohd Ali	1552	0.31	5182	10	3.34

IMPACTS OF PARTICIPATORY MANAGEMENT OF IRRIGATION AND DRAINAGE SYSTEM

Creating Farmer Organizations

The formation of FOs on 14 distributaries on Nara Canal Command Area was publicly recognized by oath-taking and handing over ceremony of thousands of water users from hundreds of villages, farmer members, leaders representing all watercourse associations and farmer organizations and politicians in the command area of all distributaries and civil society representatives. The Honorable Governor of Sindh Province chaired the Ceremony in April 2001.

Capacity Building

Based on training need assessment, the training programs arranged were: Social Organizer Volunteers (SOVs) workshop, Awareness on institutional reforms, Discharge measurement and walk thru survey (O&M), Organizational and financial management, FO rules, regulations, bylaws, action plan and Irrigation and Drainage Management Transfer agreement, Crop assessment and abiyana (Water charges) collection, and Workshops on agricultural production practices. In all 2,206 water users were trained. Majority of farmers were well experienced in farming. Most of the participants were landowners and owner cultivators; smaller number of managers, lessees and tenants participated and most of the members participated in more than one training programs.

Imputed and Actual Costs of Maintenance

The imputed cost of this activity is calculated on the typical labor and machinery hire rates prevailing at the time of the survey. Based on an average of Rs. 100 per day per person and between Rs.150-175 per tractor-hour, the grand total is just over Rs. 800,000. On an average basis the cost is almost Rs.25 per ha ($0.45) which represents about 40% of the typical irrigation water fee or abiana that farmers are expected to pay. This is a substantial saving for the government who would otherwise have had to pay those labor rates to accomplish the amount of work done. If the inputs were typical for all of Sindh then the total cost of maintenance for the Province would something on the order of Rs.125 m or $2.25 m. The details are given in table 2.

Table 2. Maintenance inputs into pilot secondary canals

Distributary	Man-days	Tractor-hours	Imputed Cost (Rs)	Earth-work (m^3)	Work (man-days per ha)	Cost (Rs/ha)	Cost (Rs/ $m^{3)}$
Heran	1157	58	124100	7411	0.23	24.85	16.74
Rawtiani	586	35	64025	1351	0.16	17.50	47.40
Bareji	1020	14	105700	5601	0.18	18.23	18.87
Mirpur	1311	120	172650	9993	0.20	26.29	17.28
Potho	979	17	113611	8138	0.30	34.80	13.96
MAW	427	30	44625	3806	0.28	28.76	11.72
Khadwari	301	16	49275	n/a	0.24	39.59	n/a
Dhoro Naro	2055	292	249375	7376	0.38	46.03	33.81
Total	7836	582	923361	43678			
Average					0.25	29.51	22.83

Hydraulic Impact of Desilting

Before desilting the average DPR at the head of the eleven canals was 1.29 (i.e. 29% above design), ranging from 213% of design at Bareji which had been remodeled in 1995 and could cope with much larger than designed discharge to 58% of design at Bagi. However, the DPR at the head of the tail sections averaged only 97% of design indicating that in most canals all of the extra water was being captured by the head and middle sections of the canal (Table 4).

After desilting, the picture changed considerably. Average discharges into canals were only 20% above design: overall in the area discharges are low after desilting because it is the coolest season of the year and wheat in some areas is beginning to mature. However, tail end DPR values were, on average, also at 120% of design indicating almost uniform distribution. Data demonstrate that the inequity between head and tail was substantially reduced. However, many tail end areas got more water than the head, but in reality this will slowly be reversed as canals silt up again during the year.

Table 3. Hydraulic condition of the distributaries before and after maintenance

Distributary	Before Desilting			After Desilting		
	Head	Tail	Ratio of Head:Tail	Head	Tail	Ratio of Head:Tail
Heran	1.36	0.38	**3.53**	1.31	0.51	**2.55**
Rawtiani	1.71	1.71	**1.00**	1.54	1.71	**0.90**
Tail	1.49	1.20	**1.23**	1.15	0.96	**1.20**
Mirpur	1.02	0.39	**2.64**	0.94	0.66	**1.44**
Bareji	2.13	1.63	**1.30**	2.13	2.36	**0.90**
Sanrho	1.29	1.11	**1.16**	1.34	1.58	**0.85**
Belharo	1.11	0.36	**3.07**	1.07	0.79	**1.35**
Digri	1.17	1.12	**1.04**	1.04	0.90	**1.16**
Potho	1.02	1.28	**0.79**	0.74	0.98	**0.76**
Khatian	1.31	0.65	**2.00**	1.25	1.35	**0.92**
Bagi	0.58	0.80	**0.72**	0.71	1.36	**0.52**
Average	**1.29**	**0.97**	**1.68**	**1.20**	**1.20**	**1.14**

Reform Progress in Sindh

Experience of pilot project has lead to the formation of new canal area water boards and farmer organizations in the Province of Sindh, Pakistan. The newly established AWB and FOs are given in the table 4.

Table 4. Newly established canal area water boards under institutional reforms in Sindh

Area water Board	Barrage	CCA (Acres)	Designed Discharge (cusec)
NaraCanal Year of Establishment: 1999 FOs to be formed: 165 FOs registered: all	Sukkur	2493,029	13,600
Left Bank Canal Circle Year of Establishment: 2002 FOs to be formed: 123 FOs so far registered:05	Kotri	1,533,935	18,956
Ghotki Feeder Canal Year of Establishment: 2002 FOs to be formed: 64 FOs so far registered: 06	Guddu	855,231	8,490
Western Canal Year of Establishment: 2002 Total FOs to be formed: 183 (Board is yet to function)	Sukkur	1,070,623	13,800
Begari Feeder Canal Year of Establishment: 2002 FOs to be formed: 85 (The board is yet to function)	Guddu	958,857	14,764

LESSONS LEARNED

It is also clear that in a comparatively short period of time, and certainly in no more than two or three days if people work hard, it is possible to completely desilt secondary canals and restore them to some measure of their original design condition. This level of input does not seem unreasonable and we can speculate that if other conditions remain in place then it will be possible to expect similar inputs into the future.

There were substantial hydraulic benefits. In virtually all locations the inequity of water distribution between head and tail was reduced, and in several cases previous inequities were reversed with tail end water users getting a slightly higher proportion of available water than head enders.

CONCERNS FOR THE FUTURE

It would, however, be unwise to be complacent about the situation that was measured and observed during the January 2000 maintenance period. A number of issues remain that continue to cast doubt on the ability of Farmer Organizations to maintain their facilities now that management transfer has occurred.

Even on those canals where IWMI had undertaken physical surveys of cross-sections and longitudinal sections desilting remained more a matter of eyeballing than of systematic and controlled establishment of design sections. The desilting was done up to a point where the profile looked more or less smooth, banks were shaped to look correct, weak sections were strengthened, and in a limited number of places, the cross-section was made narrower. Yet at no time were physical measurements taken to determine whether widths, depth or slopes were consistent with what should be required to provide effective water levels at each outlet when the canal operates at design discharge.

Although hydraulic conditions improved in most canals, these results did not become inculcated into the daily actions of water users or the Irrigation Department, instead remaining more or less as a separate and unrelated measurement exercise. So the link between maintenance and performance remains weak or non-existent, and there is no sign of any major effort to try to link them again.

The maintenance efforts described here only dealt with the issue of desilting and repair of canal banks. There was no attention paid to physical infrastructure such as regulator, bridges and outlet structures which are controlling the discharge of water. To some extent this reflected the continuing stand-off between the Farmer Organizations and the Irrigation Department that prevailed at that time.

Collecting water charges from the water users and giving the agreed portion (60%) to the canal area water board and rest (40%) keep with FO to maintain the channel and run the organization is another task that farmer organizations have to take.

Based on these concerns it would be premature to suggest that the Farmer Organizations can undertake all aspects of maintenance and organizational matters and water conflicts into the future. There is still a long way to go before they develop the technical skills and the managerial capacity to maintain canals, repair infrastructure, and upgrade it as and when the need arises.

CONCLUSIONS

The institutional reforms in irrigation sector are in progress. The impact of pilot project has indicated that the FOs jointly discusses the irrigation and drainage issues in their meetings which were not held before in any formal or informal way. A good number of water users have received technical, social and financial training, which has resulted in better management of the system.

In systems with a high degree of control over water there is some opportunity for a trade-off between operation and maintenance in order to achieve the desired water distribution pattern. In the supply-based systems of the Indus Basin and northwest India this option is not available: if canals are not maintained so that their physical condition approximates the original design, it is impossible to achieve a reasonable degree of equity of water distribution.

Irrespective of who is given operation and maintenance responsibility, be it the Irrigation Department, Farmer Organizations or private companies, the basic maintenance requirements remain the same in these supply-based systems. If ownership or management responsibility changes, there is no hydraulic basis for altering the rules of operation and maintenance unless there is a change in design.

There is no shortage of information on performance parameters, their values and tolerances, that should form the basis of an integrated operation and maintenance program that achieves the desired levels of water distribution equity and predictability that are the hallmarks of a well-managed supply-based irrigation system.

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WATER WARS OVER WASTEWATER — A TEXAS CASE STUDY OF LEGAL ISSUES RELATED TO SURFACE WATER RIGHTS AND INDIRECT USE OF WASTEWATER

Lyn E. Dean[1]

ABSTRACT

Comprehensive regional water planning in Texas over the last several years has confirmed what many already knew – populations are expected to continue to grow and the water resources of the state will be stretched to their limits over the next fifty years. Once considered a threat to surface water supplies because of water quality concerns, treated wastewater effluent discharged into Texas rivers from municipal wastewater treatment plants is now viewed by many as critical to the ability of water suppliers to meet the projected growth in water demands. Who has the right to claim legal control over the effluent for subsequent use downstream once it is returned to the watercourse is one of the most hotly contested water rights issues facing Texas water planners, regulators, judges, and lawmakers. Issues that must be resolved include: (1) what entity should be awarded legal rights, if any, to return flows; (2) what types of conditions can be imposed on such a right to protect existing water rights and the environment; (3) should reuse authorizations be treated as new appropriation; (4) should future increases in effluent discharges or effluent from groundwater or imported waters be treated differently. This paper summarizes the existing legal framework under which these issues are being analyzed and provides a brief synopsis of the statewide reuse disputes now pending in Texas.

INTRODUCTION: BASIC TEXAS WATER RIGHTS

In Texas, surface waters are owned by the State[2] and their use is generally authorized by permits issued by the Texas Commission on Environmental Quality (TCEQ). As with many of the western states, Texas generally uses the prior appropriation approach of "first in time, first in right" to authorize use of surface water.[3] The most fundamental principal of this approach is that "the right to the

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[2] *See* TEX. WATER CODE § 11.021 (defining "state water"); *see also* 30 TEX. ADMIN. CODE § 297.1(50) (clarifying that "state water injected into the ground for an aquifer storage and recovery project remains state water" but "State water does not include percolating groundwater; nor does it include diffuse surface rainfall runoff, groundwater seepage, or springwater before it reaches a watercourse.")

[3] Although not directly relevant to the reuse issues addressed in this paper, it should be noted that Texas actually employs a hybrid system that continues to

use of **state water** may be acquired **by appropriation"** only in the manner and for the purposes provided for Texas statutes.[4] Except in a few limited circumstances,[5] "no person may **appropriate** any **state water** or begin construction of any work designed for the storage, taking, or diversion of water without first obtaining a permit from the commission to make the appropriation."[6] An application for a permit may only be granted upon a finding that the application meets the statutory requirements, that water is available, and that the proposed appropriation is for a beneficial purpose, does not impair existing water rights, is not detrimental to the public welfare, is consistent with the state and regional water plans, addresses water conservation concerns, and includes proper consideration of environmental needs.[7]

LEGAL BASIS FOR REUSE

Direct Reuse

The use of water that remains unconsumed after the water is used for its original authorized purpose of use and before that water is either disposed of or discharged or otherwise allowed to flow into and intermingle with other state waters is commonly referred to as "direct reuse."[8] In Texas today, it is undisputed that a water right holder may directly reuse and fully consume effluent subject only to the limitations contained in the underlying water right from which the effluent was derived.[9] Specifically, Texas Water Code § 11.046(c), states that, unless otherwise provided in a permit,

> water **appropriated . . .** may, **prior to its release into a watercourse** or stream, be beneficially used and **reused** by the holder of a permit, certified filing, or certificate of adjudication for

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recognize some limited common law riparian rights to use surface water for domestic and livestock purposes, *see generally* Lyn Dean, *Domestic and Livestock Use: What Rights Does My Client Have Left*? 33 TEX. ENV. L. J. 175 (Summer 2003).

[4] *See* TEX. WATER CODE ANN. § 11.022 (emphasis added).

[5] *See id.* §§ 11.142, 11.1421, and 11.1422.

[6] *Id.* § 11.121; *see also* 30 TEX. ADMIN. CODE § 297.l(4) (defining **"appropriative right"** as "the right to impound, divert, store, take, or use a specific quantity of state water acquired by law."

[7] *See* TEX. WATER CODE ANN. § 11.134(b).

[8] *See* 30 TEX. ADMIN CODE § 297.1(44) (defining "reuse"); *see also id.* § 297.1(47) (defining "Secondary use" as "the reuse of state water for a purpose after the original, authorized use.")

[9] The water right holder may need a reuse authorization under 30 TEX. ADMIN. CODE Chapter 210, which regulates direct reuse from a human health perspective, or some type of water quality permit, however. The requirement for a water right and the requirement for a Chapter 210 permit are separate requirements.

> the purposes and locations of use provided in the permit, certified filing, or certificate of adjudication.[10] **Once water has been diverted** under a [water right] and **then returned to a watercourse or stream, however, it is considered surplus water[11] and therefore subject to reservation for instream uses or beneficial inflows or to appropriation by others** unless expressly provided otherwise in the permit, certified filing, or certificate of adjudication. (Emphasis added.)

Indirect Reuse

"That portion of **state water** diverted from a water supply and beneficially used which is not consumed as a consequence of that use and returns to a watercourse" is known as "return water" or "**return flow.**"[12] Return flow includes sewage effluent that is discharged back into a watercourse.[13] The subsequent downstream diversion and use of effluent return flows is commonly referred to as "indirect reuse." Although, as discussed above, Texas law allows direct reuse, the ability to which indirect reuse effluent may be allowed is at issue statewide and is the focus of the remainder of this paper.

The primary focus of most requests to obtain indirect reuse rights has been on section 11.042 of the Texas Water Code[14] – the "Bed and Banks" statute – which some argue provides an independent basis for granting indirect reuse authorizations outside the established prior appropriations permitting scheme.

Section 11.042 contemplates the issuance of permits for the delivery of certain waters down the bed and banks of a watercourse under three separate circumstances. Specifically, in pertinent part, the statute provides:

> (b) A person who wishes to discharge and then subsequently divert and reuse the person's **existing return flows derived from privately owned groundwater** must obtain prior authorization

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[10] TCEQ's current definition of "municipal use" allows use of reclaimed water in lieu of potable water for any purpose within the municipal use definition. *See* 30 TEX. ADMIN. CODE § 297.1(32). Reclaimed water is "Municipal or industrial wastewater or process water that is under the **direct** control of the treatment plant owner/operator, or agricultural tailwater that has been collected for reuse, and which has been treated to a quality suitable for the authorized beneficial use." 30 TEX. ADMIN. CODE § 297.1(39).

[11] Surplus water is defined as "water in excess of the initial or continued beneficial use of the appropriator." TEX. WATER CODE § 11.002(10); 30 TEX. ADMIN. CODE § 297.1(53).

[12] 30 TEX. ADMIN. CODE § 297.1(43).

[13] *Id.*

[14] *See also* 30 TEX. ADMIN. CODE § 297.16.

> from the commission for the diversion and the reuse of these return flows. The authorization may allow for the diversion and reuse by the discharger of existing return flows, less carriage losses, and shall be subject to special conditions if necessary to protect an existing water right that was granted based on the use or availability of these return flows. Special conditions may also be provided to help maintain instream uses and freshwater inflows to bays and estuaries. A person wishing to divert and reuse future increases of return flows derived from privately owned groundwater must obtain authorization to reuse increases in return flows before the increase.
>
> (c) Except as otherwise provided in Subsection (a) of this section, a person who wishes to convey and subsequently divert **water** in a watercourse or stream must obtain the prior approval of the commission through a bed and banks authorization. The authorization shall allow to be diverted only the amount of water put into a watercourse or stream, less carriage losses and subject to any special conditions that may address the impact of the discharge, conveyance, and diversion on existing permits, certified filings, or certificates of adjudication, instream uses, and freshwater inflows to bays and estuaries. Water discharged into a watercourse or stream under this chapter shall not cause a degradation of water quality to the extent that the stream segment's classification would be lowered. . . ..
>
> . . .

<u>Indirect Reuse of Groundwater-Derived Effluent</u>. Section 11.042(b)'s authorization of reuse of groundwater-based effluent essentially tracks the decision by Texas Natural Resource Conservation Commission (TNRCC) (predecessor to the TCEQ) in the *City of San Marcos* case, a decision issued prior to the enactment of this statute. In that case, the City of San Marcos sought a bed and banks authorization to convey treated groundwater-derived wastewater discharged from the City's wastewater treatment plant approximately two miles downstream, then divert up the "effluent" (minus conveyance losses). In that case, the TNRCC decided that San Marcos might obtain the reuse authorization (with appropriate streamflow restrictions) to the extent it increased its groundwater-based discharges in the future over the historic level of discharges upon which existing downstream rights had come to rely.

Although the statute today tracks this approach, the TCEQ's decision based on prior law was recently overruled by a state appellate court and is on appeal to the Texas Supreme Court.[15] In its decision, the Court concluded that, absent specific

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[15] *City of San Marcos v. TCEQ*, 128 S.W.3d 264 (Tex. App. – Austin, pet. filed).

statutory authority such as that included in the current statute, there is no common-law right to retain ownership of groundwater-derived effluent once discharged into a state watercourse.[16] In the *San Marcos* case, the Court was particularly concerned that the City's reuse project depended on mixing its effluent with the spring-fed waters of the San Marcos River, and held that, contrary to the City's and TCEQ's assertions, the effluent was not fungible with the State's water in the river.[17] The court's holding instead suggests that the only rights the City could obtain to its effluent, once discharged, were through a request for a new appropriation of state water, stating that, "unless the owner of discharged effluent can identify the location of the effluent in the watercourse — and divert it before it commingles with state water – it is presumed to become state water."[18] The City's declared intent to retain ownership of its effluent could not defeat the Court's conclusion that, once discharged into a state watercourse, effluent is abandoned as a matter of law and becomes part of the normal flow of a river.[19]

<u>Indirect Reuse of Surface Water-Derived Effluent.</u> The only significant agency precedent addressing indirect reuse of surface water-derived effluent involves a dispute over accounting of storage rights in Lake Grapevine near Dallas. In that case, the Executive Director initiated amendments to add an accounting system to the permits covering all of the storage rights in the lake. The City of Grapevine claimed a right to store and reuse wastewater discharges into a tributary of Lake Grapevine. Relying on section 11.046(c) of the Texas Water Code, the Commission ruled that, absent a specific authorization to reuse its return flows, Grapevine's return flows were available for other users and were to be treated as inflows to Lake Grapevine available to the water rights holders based on the prior appropriations doctrine.[20]

In a handful of other cases, the Commission has granted (uncontested) permits for indirect use of wastewater effluent. In these cases, the permittees have either obtained a contract to purchase the effluent from the downstream water right holder or was also the water right holder who would otherwise have been entitled

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[16] *Id.* at 266, 279.
[17] *Id.* at 276.
[18] *Id.* at 277.
[19] *Id.* at 276-78.
[20] *See* TEX. NAT. RES. CONS. COMM'N, *An Order granting the Executive Director's Petition to Amend Certificate of Adjudication No. 08-2363 of Dallas County Park Cities Mun. Util. Dist., Certificate of Adjudication No. 08-2458 of City of Dallas, and Certificate of Adjudication No. 08-2362 of City of Grapevine,* Docket Nos. 95-1626-WR, 96-1017-WR (April 4, 2000).

under the *Lake Grapevine* approach to appropriate the effluent as a senior downstream water right holder.[21]

Based on this agency precedent, one could persuasively argue that, when read together, sections 11.042 and 11.046, as amended by the Texas Legislature in 1997, generally codify the existing common law and the agency's approach. Generally speaking, as state water that is returned to a watercourse, many argue that effluent return flows are, by statute, "considered surplus water" under Section 11.046(c). Thus, those opposed to the granting of water rights for the indirect reuse of surface water argue that such return flows should be treated as available for use by other downstream water rights holders or subject to new appropriation. These opponents contend that section 11.042(c) does not offer any independent basis for laying claim to return flows. This interpretation seems consistent with the common law, which held that an appropriator had no claim to water that had escaped his land, particularly once it drained into a natural watercourse.[22]

Advocates of indirect reuse point to the fact that these statutes were amended to argue that subsection 11.042(c) now provides a legal means to obtain indirect reuse rights for surface water-derived effluent. Applicants seeking a legal right to claim return flows argue that the bed and banks authorization does not constitute a new appropriation of state water and that the protections embedded in section 11.042(c) are sufficient to protect the environment and all existing water rights holders. Further, applicants argue that, because a water right holder is entitled to consumptively use 100% of the water granted under an appropriative right (unless otherwise expressly limited in the permit[23]), and because all requests for new appropriations are evaluated assuming that the waters under these existing rights will be fully consumed (i.e. there will be no return flows), then a bed and banks permit is the proper mechanism for granting legal rights to indirect reuse of effluent and "priority" is irrelevant.

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[21] *See Water Use Permit No. 4266, as amended, of the City of Abilene* (relying on contract whereby reuser compensates downstream water right holder for impact on dependable yield of downstream senior reservoir) (amended March 6, 2003); *Water Use Permit No. 5772 of Coleman Independent School District* (Dec. 9, 2002); *Certificate of Adjudication No. 06-3256B of Athens Municipal Water Authority*(involving interbasin indirect reuse of effluent from a city by the city's municipal utility)

[22] *See* WELLS A. HUTCHINS, THE TEXAS LAW OF WATER RIGHTS 155 (1961). *See also* Ronald A. Kaiser, *Texas Water Marketing in the Next Millennium: A Conceptual and Legal Analysis,* 27 TEX. TECH L. REV. 181 (1996) ("As soon as the water leaves the appropriator's land or flows unimpeded into a natural watercourse, it becomes state water available for reappropriation."); *South Texas Water Co. v. Bieri,* 247 S.W.2d 268, 272-73 (Tex. Civ. App. – Galveston 1952, writ ref'd n.r.e.).

[23] *See* TEX. WATER CODE ANN. § 11.046.

Impact of *San Marcos* decision. TCEQ and various proponents of indirect reuse rights have argued that the *City of San Marcos* decision is limited to its facts and applies only to historical bed and banks applications for groundwater-derived effluent filed before the statute was amended. Although the Court in the *San Marcos* case acknowledged that the City of San Marcos' application concerning indirect reuse of groundwater-derived effluent might yield a different result under Senate Bill 1, many believe that the logic employed by the Court in reaching its conclusions applies directly to surface water-derived effluent, which is not so explicitly addressed by Senate Bill 1 as groundwater-derived effluent. Specifically, the issues of fungibility and the inability to specifically retain control over the effluent after discharge so as to divert the effluent prior to its commingling with state water appear to apply just as equally to surface water-derived effluent as to groundwater-derived effluent. Integral to the Court's decision was the conclusion that the City's private rights to groundwater could not "be expanded to permit the City to discharge its effluent into the San Marcos River and then divert water downstream **without having obtained an appropriative right over that state water**."[24] Where the rights to use surface water in the first instance are derived *not* from any private ownership right, but by an express grant by the state of a usufructory right, one must ask whether the argument that an appropriative right is required for surface water-derived effluent is made even stronger by the *City of San Marcos* decision.

Reconciling the Statutory Conflict. One possible resolution of the apparent conflict between sections 11.046 and 11.042(c) of the Water Code is to identify other types of water that might be available for bed and banks authorization. Water Code Section 11.046(c) states that return flows are available for new appropriation. By contrast, section 11.042(c) appears to create a type of bed and banks permit for "water" that is neither stored water nor groundwater-derived effluent. In light of this apparent conflict, and bolstered by the *City of San Marcos* decision (which distinguished "water" from "effluent"), some argue that section 11.042(c) is best limited to surface water that is imported from another basin or to pure groundwater (not groundwater-based effluent).[25] Like a groundwater-based effluent, these water resources are "developed water" that would not otherwise be available in the basin without the efforts of the appropriator who imported it.[26] And, like groundwater-based effluent discharges,

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[24] *City of San Marcos*, 128 S.W.3d at 279 (emphasis added).

[25] This would be consistent with the *Athens* permit cited *supra* n. 21. It is also consistent with agency staff's recommendation to grant the City of Irving's request to remove a requirement from its permit to return effluent from imported water to the basin of import, which on July 7th, 2004 was referred by the agency for a contested case hearing on the merits. *See Application No. 03-4799C to Amend Certificate of Adjudication No. 03-4799 of the City of Irving.*

[26] *See generally*, SKILLERN at 79-80; *Harrell v. Vahlsing, Inc.*, 248 S.W.2d 497, 505-507 (Tex. Civ. App.– San Antonio 1952, writ ref'd n.r.e.).

only the new or increased volume of this new discharge should be eligible for reuse authorization to protect existing water right holders and the environment, which may have come to rely on these discharges. Surface water-derived effluent that originates in the same basin is distinguishable because, unlike "developed water," these waters *would* otherwise be available in the basin regardless of the efforts of the appropriator. In addition, the Legislature's specific reference to groundwater-derived effluent (which is not state water) in subsection (b) and the absence of any reference to effluent in subsection (c) supports a conclusion that in-basin surface water-derived effluent should be excluded altogether from consideration for bed and banks permitting. Instead, consistent with the *City of San Marcos* decision, any user seeking a right to make indirect use of such in-basin surface water-derived return flows should be required to obtain a new appropriative right or an amendment to an existing water right to allow such reuse, which would necessarily consider the impacts of the new or amended right on existing water rights and the environment.

PENDING INDIRECT REUSE DISPUTES

Disputes where these arguments are playing out over indirect reuse are brewing in several river basins in Texas. Brief highlights from two of the more visible disputes are outlined below.[27]

<u>Colorado River[28]</u>

Over two years ago, the City of Austin requested a bed and banks permit[29] seeking legal rights to the City's existing return flows of approximately 100,000 acre-feet. Austin proposes to use some of these return flows at its downstream power plants, some for unspecified municipal use, and some as a temporary donation to the Texas Water Trust for environmental flow purposes.[30] Today, Austin's return flows are derived from surface water diversions made pursuant to two sets of water rights: those run-of-river rights held by the City of Austin and

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[27] In addition to the specific applications discussed *infra* in the Trinity and Colorado River basins, the following applications seeking some sort of indirect reuse authorization in other Texas river basins have also been filed in other river basins: *Application No. 5827B of the City of Houston; Application No. 5807 of the San Jacinto River Authority and the City of Houston; Application No. 06-3256B, City of Navasota Bed and Banks Authorization; Application No. 5809 for Authorization to Divert Existing and Future Return Flows and Convey in the Bed and Banks of the San Jacinto River.*

[28] The Colorado River referred to in this paper is located entirely within the state of Texas.

[29] *See Application No. 5779 of the City of Austin for a Bed and Banks Permit* (filed with TCEQ on April 5, 2002 and declared administratively complete on July 22, 2002).

[30] *See* TEX. WATER CODE ANN. § 15.7031.

those stored water rights held by the Lower Colorado River Authority (LCRA) and made available for diversion by the City of Austin via a complex series of contractual agreements. LCRA filed a competing application,[31] seeking rights to both Austin's existing *and* future return flows for various uses. LCRA argues that Austin's return flows are state water once discharged, or alternatively, that the return flows have already been appropriated to LCRA under its own water rights or historically relied upon. Several entities have joined LCRA in its protest of Austin, including downstream environmental interests and upstream junior water right holders.

Trinity River

The battle in the Colorado River basin pales in comparison to the complexity of the competing demands for reuse rights to effluent in the Trinity River Basin. The dispute there has several layers of additional complexity resulting from the addition of effluent derived from imported water from adjacent basins, multiple contractual arrangements between a multitude of the applicants, statutes that purport to give certain entities ownership of the effluent from their wastewater treatment plants, and the presence of significant municipal demand downstream (i.e. Houston).[32] Cross-protests by applicants and other water rights holders in the basin have been filed in all of these proceedings. TCEQ recently referred one of these applications involving imported waters for a contested case and staff is reported to be close to recommending issuance of permits to the Tarrant Regional Water District and Trinity River Authority based on a negotiated settlement of the parties.

The draft permits for the Tarrant Regional Water District that are available for review appear to track the precedent of the Lake Grapevine case in significant respects. The draft permits read much like permits for new appropriations, containing express priority dates and expressly subject to "all senior and superior water rights. The drafts also contain significant special conditions limiting total diversions to a portion of those that can be traced as having derived from raw water originally diverted under the District's water rights. There is also a

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[31] See *Application to Amend Certificates Nos. 14-5478 and 14-5482 to Store, Divert, Use and Reuse Treated Wastewater Effluent/Return Flows Discharged by the City of Austin and Bed and Bank Authorization* (filed with TCEQ on Nov. 12, 2002).

[32] See *Application to Amend Certificates of Adjudication Nos. 08-5035 and 08-4976 of Tarrant Regional Water District*; *Application to Amend Certificate of Adjudication No. 08-4248 of Trinity River Authority*; *Applications to Amend Certificates of Adjudication Nos. 08-2456E and 08-2462G of the City of Dallas*; *Application No. 5778 to Reuse Lake Chapman-Based Wastewater Treatment Plant Effluent Water of Upper Trinity Regional Water District*; *Application to Amend Certificate No. 08-2410 of the North Texas Municipal Water District.*

minimum instream flow requirement limiting certain diversions. The draft permits also contain special conditions protecting return flows sought by the Trinity River Authority in its competing application. The result of the draft permits is that water rights for two of the Districts reservoirs are amended to increase the specific overall allowable diversion and use rights Reservoir. It remains to be seen whether the original protestants' interests have been satisfactorily addressed such that the permits can be issued without significant further revision or litigation. It also remains to be seen whether the Commission staff will take the position that these draft permits, resulting from very unique set of circumstances, could or should be the model applied to reuse requests statewide.

CONCLUSION

Although other western states have grappled with issues related to indirect and direct reuse of surface water for some time, only in the past few years has the issue crystallized for Texas water suppliers. Pending disputes and the existing statutory scheme have highlighted a number of unresolved issues that invite resolution through litigation or legislative action. These include such questions as: (1) Does the Commission possess the requisite statutory authority to grant bed and banks permits for surface water-derived effluent? (2) Should reuse authorizations subject to the prior appropriations doctrine or "out of priority"? (3) What types of conditions can be imposed on a bed and banks permit to protect existing water rights and the environment? (4) Should direct and indirect reuse be treated differently? (5) Should historical return flows be treated differently than future increases in return flows? (6) What entity should be awarded legal rights, if any, to return flows – the underlying water right holder from which the effluent is derived, the wastewater treatment provider, or the consumer of the effluent? (7) Is a re-appropriation of surface water needed to account for return flow assumptions in old permitting decisions? How Texas chooses to resolve these issues will have significant impacts on the future of water resources planning in Texas.

PUTAH CREEK ADJUDICATION WATER SUPPLY ISSUES

Roger L. Reynolds[1]
David Okita[2]

ABSTRACT

Putah Creek is the water supply for California's Solano Project. The Solano Project, constructed in the 1950's by the United States Bureau of Reclamation (USBR), consists of Monticello Dam, Lake Berryessa, Putah Creek Diversion Dam, the Putah South Canal (primary delivery facility), and the Terminal Reservoir. The first water deliveries occurred in 1959. The water right permits for the Solano Project are held by the USBR in trust for the Solano Project water users. The original water rights permit specified releases to Putah Creek and although it limited water development in the Putah Creek watershed above Monticello Dam, it subjected the Solano Project to a condition reserving water for upstream water users. The State Water Resources Control Board (SWRCB) is the permitting and licensing agency for all water rights and retains jurisdiction over the license holder for instream fish and wildlife issues.

Following construction and operation of the Solano Project, growth continued in the upper Putah Creek watershed with new landowners filing for water rights on tributary creeks. During California's six-year drought (1987-92) water levels in Lake Berryessa began to lower significantly. Conservation measures and the efficient use of existing water supplies by both urban and agricultural users became a critical area of concern. Pumping from Putah Creek by riparian landowners downstream of the Diversion Dam, in combination with the drought conditions further reduced the Putah Creek flows maintained by the Solano Project. When creek flows started to diminish during the summer months, public interest groups called for an increase in releases.

In 1990, the Solano County Water Agency and the Solano Irrigation District commenced legal action in the Solano County Superior Court to determine the rights to the use of water in the upstream tributaries and how the water rights could equitably be determined for Solano Project water users. A settlement was reached in 1995. In 1996 a trial was held in Sacramento Superior Court on Putah Creek flow requirements below the Diversion Dam. The court ruled additional flows were required. The Solano parties appealed. This paper will summarize the history, issues, trial, and settlements reached on the Putah Creek water rights issues.

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SOLANO PROJECT HISTORY

Agricultural development blossomed in Solano County after the Gold Rush. Solano County was between the gold fields in the Sierra Nevada and the San Francisco Bay Area. As communities began growing in the Bay Area there was an increasing demand for the crops that could be grown in Solano County. Following the development of the turbine pump in the early 1900's, groundwater wells were drilled and pumping in the Putah Creek Fan, the triangular area between Winters, Davis, and Dixon, southerly of Putah Creek increased tremendously. Groundwater levels began dropping when the water pumped exceeded the natural recharge to the basin. Leaders in Solano County realized there was a need to develop additional water supplies to maintain the agricultural productivity and the local economy. During the 1940's the Solano County Board of Supervisors established a Solano County Water Council to review the water supply situation and opportunities to develop additional water supplies. Primary discussions centered on developing a project, the Solano Project, which would utilize Putah Creek flows. In February 1948, following recommendations by the council, the Solano Irrigation District was formed, with the goal to obtain irrigation water from the proposed Solano Project. The Solano Project was authorized by the Secretary of the Interior in November 1948. The Solano County Board of Supervisors established the Solano County Flood Control and Water Conservation District in 1951 as the contracting entity for the water supplies envisioned by the Solano Project.

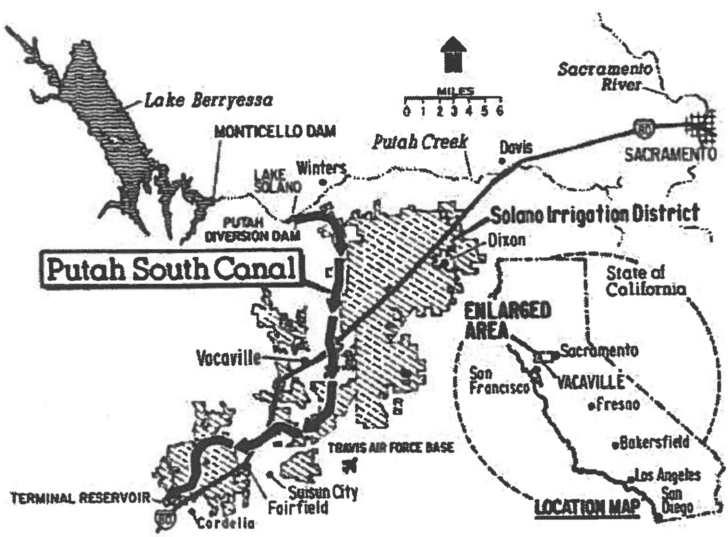

Figure 1. Location Map

The Solano Project was constructed by the United States Bureau of Reclamation (USBR) in the late 1950's. It was designed to conserve and put to beneficial use the runoff from the Putah Creek watershed. The project provided water supplies for the agricultural, municipal, and industrial needs of Solano County and recreational opportunities at Lake Berryessa. The principal project facilities are Monticello Dam and its reservoir, Lake Berryessa, the Putah Diversion Dam, and the Putah South Canal which conveys water to the agricultural and urban member units of the Solano County Flood Control and Water Conservation District, reorganized into the Solano County Water Agency (SCWA) in 1989. The agricultural users are the Solano Irrigation District and the Maine Prairie Water District, and the urban users are the cities of Vacaville, Fairfield, Suisun City, and Vallejo. The Putah Creek watershed upstream of Monticello Dam is 576 square miles. The annual deliveries from the project are approximately 200,000 acre-feet. Of this total, the Solano Irrigation District (District) with approximately 56,000 irrigable acres receives approximately 151,000 acre-feet per year. The location of Solano Project facilities and the District, are shown in Figure 1.

SOLANO PROJECT WATER RIGHTS

The Solano Project was designed and built on the basis of a 40-year operation study from 1915-16 through 1954-55, which assumed the average annual Putah Creek runoff at 309,500 acre-feet. Estimated reservoir evaporation losses and releases down Putah Creek to satisfy prior riparian water rights determined an available supply of 247,000 acre-feet per year. Decision 869 adopted by the State Water Resources Control Board on February 7, 1957, authorized the USBR to store 1,600,000 acre-feet in Lake Berryessa behind Monticello Dam. Stored water is released down the creek to Putah Diversion Dam where it is diverted into the Putah South Canal with some minor releases into lower Putah Creek.

The water rights permits issued under Decision 869 were subject to several different conditions. One condition makes a reservation of stream flow above Lake Berryessa of 33,000 acre-feet for use by water users in the upper Putah Creek watershed. One State Water Resources Control Board memo from 1962 states, "*The 33,000 acre-feet reservation was to be considered as net stream depletion and was to be deducted from the 247,000 acre-feet safe yield developed by Monticello project.*"

Another permit condition issued under Decision 869 required the release of enough water down Putah Creek to 1) meet prior riparian rights, and 2) to be sufficient to maintain the same percolation of water into the groundwater basin as occurred under pre-project conditions. The amount of water required to meet this condition was controversial from the start, and the USBR was required to conduct an extensive and detailed monitoring program to assure the adequacy of the releases. This was to include stream gaging, groundwater quality monitoring, and computations on groundwater storage changes. The SWRCB reserved their jurisdiction over this issue for a 15-year period to allow an opportunity to review the data collected and change the required release of water below the Diversion Dam if needed. Another permit term required USBR to maintain a live stream *"as far below the diversion dam as possible, consistent with the purposes of the project and the requirements of downstream users."* The intent was to release enough water to maintain the flow in the creek to the Yolo Bypass whenever the inflow to Lake Berryessa was sufficient.

Determination of the required releases under the live stream scenario was difficult for the USBR to implement due to the highly varied and unpredictable inflow into Lake Berryessa from its numerous tributaries. This was also complicated by the difficulty in estimating the downstream demand requirements. The USBR filed a petition with the SWRCB in 1969, 12 years after Decision 869 was approved, to set aside the live stream flow releases and replace them with a monthly schedule of releases as follows:

Period	Normal Year (cubic feet per second (cfs))	Dry Year* (cfs)
November through January	25	25
February	16	16
March	26	26
April	46	46
May through July	43	33
August	34	26
September and October	20	15

Normal Year releases are 22,145 acre-feet, while Dry Year releases are 19,223 acre-feet.

No opposition to the above release schedule was presented at the public hearing in 1969 and in 1970 the SWRCB adopted the above fixed release schedule and also relieved the USBR of some of their monitoring requirements.

PUTAH CREEK ISSUES

In 1970 when the SWRCB adopted the fixed release schedule, they again retained jurisdiction over the release schedule. In 1976 and 1977 California experienced the driest two year drought since construction of the Solano Project. Concerns regarding water supply needs for cities, agriculture, and the environment began to be heard. At a SWRCB hearing held in 1978 to review whether or not the 1970

* When inflow into Lake Berryessa is less than 150,000 acre-feet

release schedule was supplying sufficient water to Putah Creek, arguments were presented to increase the releases. The Putah Creek Riparian Landowners/Water Users wanted to increase the release schedule claiming existing operations were impacting recharge to the groundwater basin. The University of California at Davis mentioned water levels on the north side of Putah Creek were lowering, increased releases would benefit, and continued monitoring of the impacts was needed. Testimony on fishery issues in Putah Creek was presented. The initial movement which would lead to the Putah Creek Adjudication had begun.

Increased growth in Napa and Lake Counties during the 70's and 80's stimulated filings for water right permits in the upper Putah Creek watershed. The water rights and supply issues in lower Putah Creek became more of a concern after groundwater levels lowered during the 1976-77 drought. The reduced groundwater levels made people wonder if there would be enough water for the agricultural needs of riparian landowners. During this period there was also an increased national consciousness to protect and maintain environmental values and to fight for public resources one felt were unfairly being impacted.

From 1987 through 1992 California entered into the longest drought the majority of the current population had ever experienced. As water levels in Lake Berryessa began dropping, concerns were raised regarding the long-term reliability of the Solano Project supplies. The increased filings for water right permits in the upper Putah Creek watershed prompted Solano Project water users to believe the 33,000 acre-foot reservation in Decision 869 would be exceeded, reducing the long-term availability of Solano Project water supplies. The drought conditions increased pumping and lowered groundwater levels causing people to question the adequacy of groundwater recharge from Putah Creek. Reduced groundwater levels in Yolo County, north of Putah Creek, also diminished the groundwater flows from Yolo County that when flowing southeasterly would be intercepted by Putah Creek. Lowered groundwater levels and reduced flows in Putah Creek made illegal diversions from Putah Creek a significant problem. The initial drought years reduced runoff into Lake Berryessa causing the Solano Project releases down Putah Creek to be reduced. The diminished groundwater inflow into Putah Creek from Yolo County along with illegal diversions reduced flows during 1989, 1990, and 1992 in Putah Creek below Stevenson Bridge to zero (See Figure 2, Lower Putah Creek). Riparian landowners and the Putah Creek Council protested, requesting USBR to increase the releases. With the uncertainty of the drought and how long it would last, the Solano County Water Users were unwilling to increase releases. News articles were written showing the dry bed of Putah Creek with dead fish. Negotiations were held and some supplemental Putah Creek water supplies were secured. Efforts to reduce illegal diversions were also pursued to help increase the flows down Putah Creek. All efforts were met with dissension and differing opinions on who was at fault and what should be done.

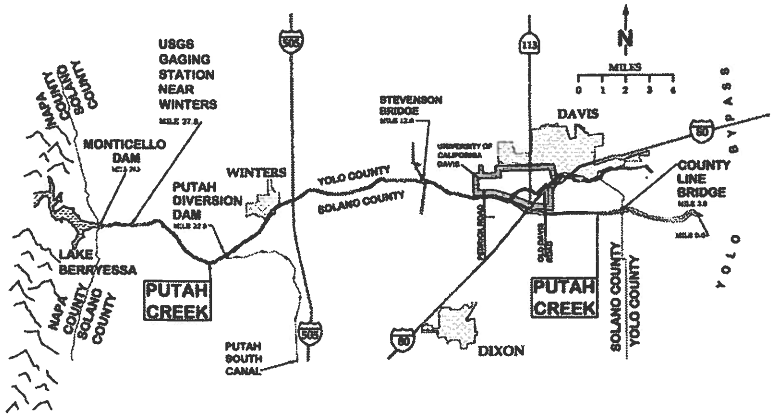

Figure 2. Lower Putah Creek

The average annual Putah Creek flows pre-project, 1906-58, were over 358,000 acre-feet. Post project, 1959-91, annual Putah Creek flows below the Diversion Dam had averaged approximately 152,700 acre-feet. Landowners along Putah Creek believed the lowered groundwater levels directly related to this reduction and the only way to improve the situation was to increase the releases.

LITIGATION

Due to the continuing unresolved Putah Creek water supply and water right issues, in April 1990, the Solano County Water Agency, Solano Irrigation District, the cities of Vallejo, Vacaville, Fairfield, and Suisun City, and the Maine Prairie Water District jointly filed a complaint in the Sacramento Superior Court for adjudication of all Putah Creek water rights. The adjudication was initiated to resolve the ongoing uncertainties regarding the legal rights to Putah Creek water both upstream and downstream of Lake Berryessa. The adjudication would resolve the status of water right filings in the upper watershed tributary to Lake Berryessa, and would determine the adequacy of Putah Creek releases to maintain the rights of riparian users and the recharge of the downstream Putah Creek fan groundwater basin. It would also address challenges made regarding how much water should be released to maintain the fishery and riparian habitat in Putah Creek. In August 1990 the Putah Creek Council, founded in February 1988 by people interested in protecting Putah Creek's riparian habitat and the water flows in the creek, filed a complaint for injunctive relief to keep water flowing in lower Putah Creek for fish. The City of Davis and the University of California, Davis joined the legal efforts.

Upstream Issues

The face value of water right permit applications for tributaries in the upper watershed had exceeded the 33,000 acre-foot reservation originally included in Decision 869. The Solano Project water users felt the SWRCB should consider the upper Putah Creek watershed fully appropriated and halt all further water right applications. All of the Putah Creek water supply above Lake Berryessa originates in Lake and Napa Counties. None of the water originates in Solano County.

The original wording of the Decision 869 permit regarding water usage in the upstream watershed was disputed. The permit stated the depletion of the stream flow above the reservoir should not exceed 33,000 acre-feet. The upstream parties argued the face value of the water right permits and the actual depletion were different and that permitting should be able to continue until the actual depletion reached 33,000 acre-feet. The permit also mentioned the full appropriation of the upper watershed allocation would have to be completed prior to the *"full beneficial use of water within the project service area under this permit."* The upstream appropriators argued Solano Project water at the present time was not being put to its full reasonable and beneficial use. The Solano Project water users were in obvious disagreement arguing they were putting all of their water to its full reasonable and beneficial use.

After the suit was filed negotiations began and continued for 5 years between the Solano County Water Users, USBR, and Upper Putah Creek Water Users. The negotiations resulted in a settlement agreement in March 1995. In January 1996 the Court appointed Settlement Committee requested the State Water Resources Control Board to modify the applicable Putah Creek water rights. The Court then appointed a watermaster responsible for determining the amount of annual depletion within the upper watershed and preparing a report each year clarifying the amount of remaining reservation for each county. The settlement agreement also called for the formation of a three-member advisory committee consisting of one member from each county. The watermaster was to meet with the advisory committee, as necessary, to review any issues or questions in regard to the administration of the agreement.

Downstream Issues

Downstream issues related primarily to increasing flows in Putah Creek. Landowners, from the Diversion Dam to Davis, felt the Solano Project was not releasing enough water to maintain acceptable recharge into the Putah Creek fan. Although groundwater levels had been impacted by the drought, some Yolo County and northern Solano County landowners were convinced an increase in releases would solve their groundwater recharge concerns. The Putah Creek Council, agonizing over the drought's impact on Putah Creek's riparian wildlife habitat and fisheries, also pushed for increased flow releases. Solano County citizens, responsible for repaying the debt on the Solano Project, and dependent on Putah Creek for their daily water supplies, both urban and agricultural, did not want to damage the creek or hurt anyone, but they did want to establish, once and for all, their rights to Putah Creek water supplies.

TRIAL

Regarding the downstream issues, negotiations and legal maneuvering continued for the next six years in an attempt to reach a settlement on flow requirements. The differences were significant, however, and when it became apparent the parties would not reach a settlement, it proceeded to trial in Sacramento Superior Court in March 1996.

The trial involved numerous attorneys and consultants for all parties. Witnesses included experts on hydrology to summarize the historic pre-project Putah Creek flows and how the present release schedule varies from the pre-project flows; hydrogeologists to explain how the natural groundwater flow in the basin impacts Putah Creek, and how the creek flows interact with and supply the groundwater basin; wildlife, fish, and plant specialists to discuss the existing flora, fauna, and fish along the Putah Creek riparian habitat and the impacts to each based on varying Putah Creek flow releases; and USBR, Solano County Water Agency, and Solano Irrigation District engineers and staff to describe the operation of the Solano Project and how water is supplied and delivered within Solano County.

The environmental issues (fisheries and creek habitat) were critical to the trial's eventual outcome, but one of the most interesting hydrogeologic issues was how recharge occurs adjacent to Putah Creek. As mentioned, there was a desire to increase Putah Creek flows thinking this would increase the recharge. Testimony presented at trial discussed U.S. Geological Survey research that determined water flowing down Putah Creek creates a groundwater mound or ridge beneath the creek. Historically this mound formed beneath the creek after the first significant runoff in the fall. The groundwater mound or ridge would remain as long as substantial runoff (25 cfs or more) continued down Putah Creek. Different reaches in Putah Creek were defined with different recharge characteristics. The reach from about two miles upstream of Winters to the City of Winters bridge provides the primary recharge to the older alluvium in the Putah Creek fan. This is a continually losing reach and recharge has been fairly consistent post-project due to the required flow releases and the fact the amount of water lost is determined by the percolation rate of the creek bed and not the amount of water flowing past the reach. The next reach from Winters to Stevenson Bridge is the most complex. When adjacent groundwater levels are high, a stable ridge is formed. With groundwater flowing in a southeasterly direction, groundwater pumpers on the southerly side of Putah Creek are benefited by the consistent groundwater levels. When the groundwater levels are high, Putah Creek acts like a drain intercepting the groundwater flows from the northeast. When this occurs, little if any recharge occurs, and flows in the Putah Creek channel are bypassed downstream. Typically, however, groundwater levels drop in late spring and early summer when groundwater pumping begins on the adjacent agricultural lands. The groundwater ridge beneath Putah Creek, which in wet years extends during the winter from Winters to Stevenson Bridge, begins to diminish and as the groundwater levels drop the reach changes from a gaining reach, intercepting groundwater flows from the northwest, to a losing reach providing recharge to the Putah Creek fan. Seepage loss analyses indicate losses in this reach vary from approximately 0 up to 15 cubic feet per second. However, the percolation is dependent on the actual length of the losing reach, which is dependent on groundwater levels, not on the quantity of flow down the creek. Studies have indicated the next reach to about Pedrick Road is always a losing reach, and the last reach from Pedrick Road to the Yolo Bypass has little percolation. This testimony, generally accepted by experts on both sides, was central to the eventual ruling and the settlement of the adjudication.

Ruling

At the conclusion of five weeks of trial, the judge described Putah Creek as a treasure, a full ecosystem in the middle of an agricultural environment, a place where people could go to watch birds, fish, recreate, and enjoy the sights, sounds and smells of nature. He also mentioned Putah Creek and its water were vital to Solano County, providing a domestic water supply for many of its cities and water for agricultural production benefiting the economic health of the county. He summarized what he had learned about Putah Creek flows and the Putah Creek environment before and after completion of the Solano Project. In the pre-project period there were high winter and spring flows and in the summertime continuous flows down to some point near Winters. Further downstream there were discontinuous pools of water in reaches which were augmented by rising groundwater. Native fish adapted to this flow and thrived.

The judge was in agreement with the U.S. Fish and Wildlife Service and University of California experts that the flows in the 1970 release schedule were not sufficient to keep the creek fish in good condition. Although credible evidence was submitted that the release schedule provided more water than pre-project conditions for the end of the summer months, the judge felt the lack of consistent high flows hampered the vegetation and recreational values of the creek, particularly during drought years. Although testimony was presented that public trust issues did not apply, the judge disagreed and concluded the present release schedule was not sufficient to satisfy the public resources associated with Putah Creek.

Solano interests had wanted to maintain the existing release schedule. Putah Creek Council had asked for a dramatic increase in releases. The judge felt a balance or compromise was needed. Testimony had shown Solano County parties were able to conserve water and make adjustments to meet their water supply needs during the 6-year drought. Testimony had also been presented showing Solano County agricultural interests could pump additional groundwater to augment their water supply requirements. Therefore, the judge felt an increase in flows could be made without significantly impacting Solano interests and supported the establishment of a perennial flow from the Diversion Dam to the Yolo Bypass. He also supported additional flows for rearing and spawning fish, but would not support flushing flows or a significant increase in flows to support anadromous fish. He estimated the increased flows for rearing and spawning flows would only increase the required annual releases to approximately 32,657 acre-feet, 10,511 acre-feet more than under the present release schedule. An injunction was issued to increase the flows.

Settlement

The Solano parties appealed this ruling, but over the next 4 years entered into settlement discussions with the other parties to define the terms of the increased flows required for Putah Creek. Negotiations concluded in 2000 with the signing of a Putah Creek Accord resolving all of the disputes. This was a detailed agreement establishing the terms of the permanent injunction governing the required release of water at the Diversion Dam into Putah Creek for fish rearing flows and the minimum flow regime that would have to be maintained and monitored in lower Putah Creek. Larger three-consecutive-day pulse flow releases between February 15 and the end of March are required for spawning flows. Lower flow releases were established when storage in Lake Berryessa reduced below 750,000 acre-feet (47% of capacity). The Solano parties were to provide in perpetuity $40,000 per year for a Streamkeeper and an additional $120,000 per year to fund fish and wildlife monitoring and vegetation enhancement projects. A Lower Putah Creek Coordinating Committee (Committee) was formed with ten representative members, five from Yolo County and five from Solano County, to address ongoing Putah Creek issues. A notice to riparian landowners was authorized stating Solano would bring legal action against any illegal diverter whose actions negatively impacted the ability of the Solano Project to meet its obligations under the agreement.

Although supplemental flows for anadromous fish had originally been dismissed at trial, the Settlement provides, with some restrictions, for supplemental flows for anadromous fish. These flows are significantly less than the flows originally requested at trial. This situation, however, has created one last issue which still needs to be resolved. The Settlement Agreement recognized some of the new supplemental flows down Putah Creek were for the purpose of attracting and rearing anadromous fish such as steelhead. Steelhead is now listed as a threatened species under the Federal Endangered Species Act. The Agreement provides limitations on Committee activities until Solano is able to obtain assurances from the National Marine Fisheries Service that if any supplemental flows do attract steelhead to Putah Creek, Solano will not be forced to release any additional water to improve the Putah Creek habitat for the new steelhead.

Over the last four years the Committee has exceeded expectations as an organization. A Streamkeeper was hired and numerous grants have been received to help enhance the Putah Creek riparian habitat. The restoration activities are gaining attention statewide, as a model of cooperation between a water supplier and downstream environmental interests.

GRAND VALLEY WATER MANAGEMENT PROJECT

Brent R. Uilenberg[1]
Robert E. Norman[2]

ABSTRACT

The Grand Valley Water Management Project (Project) consists of irrigation system improvements which provide the ability to reduce irrigation diversions from the Colorado River. The concept behind the Project was originally developed through a study conducted under the Bureau of Reclamation's General Investigations Program in cooperation with the Grand Valley Water Users Association and California Polytechnic State University. The Project was subsequently adopted by the Upper Colorado River Recovery Implementation Program as a key component in the overall strategy to provide flow augmentation to critical habitat reaches of the Colorado River. The Project concept was previously reported in a paper presented at the October 1998 USCID Conference.[3] Project performance and cost effectiveness is exceeding expectations. When totally completed, the Project will conserve water at a unit cost of approximately $ 9 per acre-foot per year. This paper provides a brief background on the technical aspects of the Project but primarily focuses on actual performance and institutional agreements required to implement the Project. Potential future applications of this highly cost effective concept to address environmental and/or human water uses are also briefly discussed.

BACKGROUND AND SETTING

The 15-Mile Reach of the Colorado River extends from the Grand Valley Irrigation Company diversion dam downstream to the confluence with the Gunnison River (see Figure 1). Five entities divert water from the Colorado River to irrigate approximately 69,000 acres of land in the Grand Valley. The Grand Valley Project, a Federal Bureau of Reclamation (Reclamation) project, provides water to about 60 percent of this irrigated acreage. Annual irrigation and hydropower diversions average 698,000 acre-feet. These diversions contribute to the severely depleted flow regime in the 15-Mile Reach.

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[3] Brent Uilenberg and Karen Fogelquist, Win-Win Water Supply Solution for Endangered Species Recovery in the 15-Mile Reach of the Colorado River (Proceedings U.S. Committee on Irrigation and Drainage 1998 Conference on Shared Rivers)

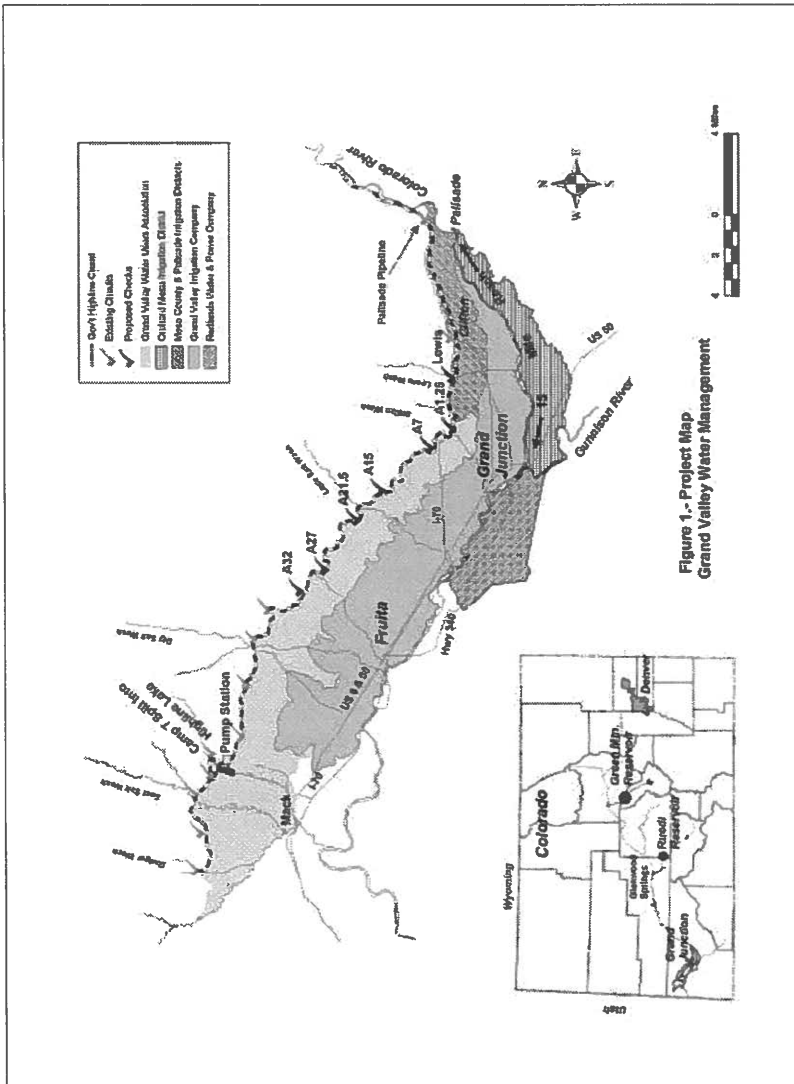

Figure 1. Project Map, Grand Valley Water Management

PROBLEMS AND OPPORTUNITIES

The diversion and consumptive use of water, along with other environmental factors, has resulted in the population decline of native fishes. Four of these species are currently listed as endangered under the Endangered Species Act. The 15-Mile Reach is considered important habitat for the recovery of two of the listed fish species, the razorback sucker and the Colorado pikeminnow. In the mid-1980's it was recognized that water development was heading for a confrontation with the Endangered Species Act. As a result state and Federal entities developed the Upper Colorado River Recovery Implementation Program (Recovery Program). The Recovery Program has the dual objectives of recovering the four listed species while the Upper Basin States continue to develop their Colorado River Compact entitlements.

As part of the Recovery Program, Reclamation conducted an appraisal-level evaluation of water supply alternatives for the 15-Mile Reach.[4] A wide range of alternatives were identified and evaluated. From technical, socio-economic and political perspectives water conservation appeared to be the most attractive alternative. Because of their location immediately above the 15-Mile Reach and because they are the last major diversion from the Colorado River within the State of Colorado, the Grand Valley irrigation systems and associated relatively senior water rights presented unique water conservation opportunities.

The primary feature of the Grand Valley Project is the Government Highline Canal. The canal has an initial capacity of 1,620 cubic-feet-per-second (cfs) and extends approximately 55 miles from the diversion dam above the 15-Mile Reach to its end near the Colorado-Utah state line. This distance translates into an approximate 72 hour transit time from the point of diversion to the end of the canal. Due to the length of the canal and the lack of control and monitoring systems, it was physically impossible to closely match river diversions with fluctuating irrigation demands. Furthermore, because of an inadequate number of check structures, it was not possible to maintain the minimum water surface elevation required to serve the irrigation laterals at low flow rates. As a result of these deficiencies approximately 70,000 acre-feet of water was diverted above the 15-Mile Reach and spilled into waste ways.

GRAND VALLEY WATER MANAGEMENT PROJECT

Based on the results of the appraisal-level evaluation, a detailed study was initiated. The study was conducted by the Grand Valley Water Users Association, California Polytechnic State University and Reclamation. The first phase of the study consisted of a detailed inventory of diversions, spills and water deliveries. A

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[4] Bureau of Reclamation, Study of Alternative Water Supplies for Endangered fishes in the 15-Mile Reach of the Colorado River, January 1992.

hydrologic/hydraulic model was then developed based on the inventory data and the physical parameters of the canal system. Various canal system improvements and operating strategies were modeled to estimate potential diversion reductions. Preliminary cost estimates were prepared for each system configuration. Based on these analyses, a preferred system configuration was identified that addressed water user needs and optimized costs and benefits. In September of 1998 a Final Environmental Assessment was issued for the Project, final designs were prepared in 1999 and construction was initiated in 2000.

The Project consists of seven new check structures and installation of a supervisory control and data acquisition (SCADA) system which integrates the operation of the new structures with eight existing check structures. The additional check structures and SCADA system provide the ability to maintain a minimum water surface elevation at a wider range of flows throughout the length of the canal and thereby more closely match river diversions with actual irrigation demands. The check structures and SCADA system also transform the canal into a series of storage reservoirs. When an increase in demand is detected in downstream reaches of the canal the SCADA system responds by making upstream gate adjustments to quickly respond to the increased demand.

A 100 cfs bypass pipeline, which discharges into the Colorado River above the 15-Mile Reach, was also installed and integrated into the SCADA system. This facility provides the ability to return water back to the river to benefit fish habitat if canal diversions exceed irrigation demands or conversely to increase canal flows by reducing pipeline flow to meet sudden increases in irrigation demand. The check structures, bypass pipeline and SCADA systems were completed prior to the 2002 irrigation season.

The final Project component to be constructed and integrated into the SCADA system is a 75 cfs pumping plant. The pumping plant will be located at an existing reservoir (Highline Lake) that obtains the majority of its water supply from canal spills. The reservoir has a total storage volume of approximately 3,400 acre-feet and is operated by the Colorado Division of Parks and Outdoor Recreation. Highline Lake pumping plant will provide the ability to quickly respond to peak irrigation demands in the lower reaches of the canal service area and thus reduce river diversions. This facility is scheduled for completion in June of 2004.

The detailed study projected an average reduction in canal spills and associated river diversions of 19,400 acre-feet during the critical August through October time period when flow recommendations for the endangered fish were historically not being met. Additionally the modeling projected average bypass pipeline flows of 9,000 acre-feet during this same period for a total potential 15-Mile Reach flow benefit of 28,400 acre-feet per year assuming all water could be legally protected.

Total estimated costs associated with preconstruction planning, permitting, design, construction and capitalized annual operation and maintenance expenses were $8.4 million or approximately $300 per acre-foot on a unit capital cost basis. Projected annual unit costs were $16 per acre-foot using Reclamation's 2004 fiscal year plan formulation interest rate of 4.8934 percent and assuming a 50 year replacement life cycle.

The Project presented a technically feasible, cost effective solution to meet the late irrigation season flow needs of the 15-Mile Reach; however, legal protection of the conserved water raised significant issues that needed to be addressed in order to implement the Project. Project conserved water is defined as reduced diversions resulting from operation of Project facilities. As part of its charter, the Recovery Program operates within the constraints of all applicable state and Federal regulations and therefore any legal protection mechanism or strategy had to comply with Colorado State water law. To address these issues the Recovery Program formed a team of legal and technical staff representing Federal, state and local stakeholders.

Project conserved water represents two categories of water from a legal protection perspective: 1) deliveries of stored water from upstream reservoirs that are no longer needed due to the reduced irrigation diversions, and 2) natural flow water available to the direct flow water rights that are no longer diverted for irrigation use.

The Grand Valley Project receives deliveries of stored water from Green Mountain Reservoir (see Figure 1) when natural flows are insufficient to satisfy irrigation demands. Green Mountain Reservoir is a component of Reclamation's Colorado-Big Thompson Project with a total capacity of approximately 152,000 acre-feet. This capacity is allocated to various East and West slope uses. The Grand Valley Project's status as a beneficiary of this storage facility is defined in the authorizing legislation and operating policies. By virtue of being a beneficiary, the Grand Valley Project along with other West slope water users is entitled to releases from the 66,000 acre-foot Green Mountain Reservoir Historic Users Pool (HUP). The Grand Valley Project also relies on very senior direct flow water rights decreed for irrigation, domestic and hydropower purposes.

In order to legally protect deliveries of stored water from diversion by other appropriators, the intended new use of the water (i.e. instream piscatorial) must be compatible with the beneficial uses claimed in the water storage right decree. Likewise, in order to redirect and legally protect the conserved natural flow water and apply it to a new use, the new use must be compatible with the beneficial uses and points of diversion claimed in the direct flow water right decree. In the case of Federal facilities such as Green Mountain Reservoir and the Grand Valley Project, the intended new use must also be compatible with the authorizing Federal legislation. Absent these water right attributes the owner of the water right seeking to redirect conserved natural flow water or stored water to a new beneficial use must prove non-injury to all other appropriators before the water court will award the additional decreed beneficial use. Additionally, if the proposed new use of the Federal facility is inconsistent with the authorizing legislation new authority must be obtained from Congress.

LEGAL AND INSTITUTIONAL SOLUTIONS

Obtaining a decreed change of use and expanded Congressional authority were immediately recognized as very difficult actions to achieve and therefore alternative mechanisms for legally protecting Project conserved water were developed using unconventional strategies. One of these strategies involved a water right application that was filed by the United States in Colorado water court in 1991.

During the planning phase of the Project the United States was involved in litigation associated with a water right application for an appropriative right of exchange on the Colorado River. This litigation was commonly referred to as the Orchard Mesa Check Case. The application drew numerous statements of opposition from water right owners on both the East and West Slopes of Colorado. Through a long and contentious negotiation process the co-applicants to the water right application (United States, Grand Valley Water Users Association and Orchard Mesa Irrigation District) were successful in obtaining a water court sanctioned Settlement Agreement which provided the foundation for legally protecting Project conserved water.[5]

The Settlement Agreement provides criteria for defining when a surplus storage condition exists in Green Mountain Reservoir. A surplus storage condition in this context is defined as reservoir storage contents that are projected to exceed the demands of all Green Mountain Reservoir beneficiaries. These criteria were developed by analyzing historic storage conditions in the Green Mountain Reservoir HUP during major drought years throughout it period of operation. If actual storage conditions exceed the volume required to provide a full water supply to all eligible users, a surplus storage condition can be declared by Reclamation. The Settlement Agreement further defines Operating Criteria for Green Mountain Reservoir, which along with the authorizing Federal legislation, provides the authority to enter into contracts for the disposition of surplus water.

In below average snow pack years the direct flow rights for the Grand Valley Project yield a limited amount of water to meet late irrigation season demands during the months of August through October. Under these conditions Green Mountain Reservoir HUP releases augment the water supply derived from the

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[5] Stipulation and Agreement, District Court, Water Division 5, State of Colorado, Case No. 91CW247.

direct flow water rights. Therefore, reduced Grand Valley Project diversions increase the occurrences of a surplus storage condition in Green Mountain Reservoir under many hydrologic conditions. This recognition guided the negotiations in the Orchard Mesa Check Case.

In order to legally protect and deliver the Project conserved water, non-consumptive uses that are compatible with the Green Mountain Reservoir water storage rights were identified. These uses were further screened on their ability to indirectly benefit flow and habitat conditions in the 15-Mile Reach if they were supplied with surplus water from Green Mountain Reservoir.

Using this criteria, two uses were identified which would provide the mechanism to legally protect deliveries of surplus storage water and indirectly benefit fish habitat. The first was the Grand Valley Power Plant, a component of the Grand Valley Project. This plant, with an 800 cfs capacity discharges water immediately above the 15-Mile Reach. The water right for the power plant has a relatively junior priority water right and frequently has unused capacity during the late summer months. The second use was instream municipal recreation which is recognized as a valid beneficial use under Colorado water law.

The identification of these uses led to the negotiation of water service contacts for delivery of stored water from Green Mountain Reservoir. The first contact, between the United States, Grand Valley Water Users Association and the Orchard Mesa Irrigation District provides for the delivery of water to the Grand Valley Power Plant. It requires that all water declared to be surplus to the needs of the Green Mountain Reservoir HUP must first be delivered to the power plant to the extent unused capacity exists. The second contract, between the United States, Town of Palisade Colorado, City of Grand Junction Colorado and Town of Fruita Colorado, provides for the delivery of surplus water for instream municipal recreation uses in the Colorado River as it flows through these municipalities. Both contracts were executed in 2001. Water deliveries under both contracts indirectly result in improved flow and habitat conditions in the 15-Mile Reach.

The above discussed protection strategy involving surplus water contracts addresses the stored water component of Project conserved water but does not address the natural flow component or bypass pipeline flows. Natural flow water that is no longer needed or diverted is now available for use by other appropriators and therefore provides a more dependable water supply for water users on both the East and West slopes of Colorado. However, as was previously mentioned, the direct flow irrigation water right for the Grand Project yields only minor amounts of water during the late summer months of below average runoff years. In above average runoff years these rights do yield a substantial portion if not the entire supply of water for the Grand Valley Project. In these types of years there is little or no need for flow augmentation to benefit fish habitat but if a need does arise surplus water is available to address those needs because there is little or no demand for flow augmentation by Green Mountain Reservoir beneficiaries. Bypass pipeline flows are available for diversion by downstream appropriators. However, due to the fluctuating nature of these flows they do not provide a dependable water supply and are not currently diverted by existing appropriators.

Construction and operation of the Project pumping plant also presented legal and institutional issues. Highline Lake is operated by the Colorado Division of Parks and Outdoor Recreation primarily for water based recreation. Water storage rights for this facility are decreed for recreation and the irrigation of park lands surrounding the lake. Using Highline Lake as a storage vessel to provide irrigation water to meet peak demands in the Grand Valley Project would constitute an expansion of the water storage rights which would require a water court sanctioned change of use decree with the associated non-injury standard. Again, it was decided not to pursue a change of use decree but rather rely on an administrative policy of the Colorado State Engineer which recognizes temporary storage of water as a means to maximize the beneficial use of water. Under this policy water can be stored for up to 72 hours by another party without a storage decree with the permission of the reservoir owner. In order to capitalize on this policy a contract was negotiated with the Colorado Division of Parks and Outdoor Recreation that provided the ability to use the top two feet of Highline Lake (320 acre-feet) as a source of water for the pumping plant. In exchange for the use of this storage space the Recovery Program paid the Colorado Division of Parks and Outdoor Recreation for the appraised value of the space and agreed to pump rate limitations, water quality maintenance parameters and minimum water storage levels to safeguard recreational use of the reservoir.

RESULTS

The detailed study projected an annual irrigation diversion reduction of 19,400 acre-feet and 9,000 acre-feet of bypass pipeline return flows resulting in a total projected potential benefit to the 15-Mile Reach of 28,400 acre-feet. The 1998 water year was selected to represent pre-Project diversions as no Project facilities had been installed and comparable diversion data sets were available from the Division 5 Office of the State Engineer for water years 1998, 2002 and 2003. All Project facilities with the exception of the Highline Lake Pumping Plant were operational for the 2002 and 2003 irrigation seasons. Table1 and 2 present actual post-project results.

Table 1. Irrigation Diversions (acre-feet)

1998	2002	2003
285,217	240,424	252,301

Table 2. Reduced Irrigation Diversions and Bypass Pipeline Flows (acre-feet)

Water Year	Reduced Irrigation Diversion	Bypass Pipeline Flow	Total Potential Benefit to 15-Mile Reach
2002	44,793	2,053	46,846
2003	32,916	10,161	43,077

The 2002 water year was a period of severe drought conditions and the Grand Valley Water Users Association had implemented a demand management program, therefore the reduced irrigation demands cannot be entirely attributed to Project facilities. However, a full water supply was available to the Grand Valley Project in 2003 and no demand management program was in place. Upon completion of the pumping plant, total potential benefits to the 15-Mile Reach are anticipated to be in the 50,000 acre-foot range.

Total actual Project costs, including the pumping plant, will be approximately $8.2 million. Annual unit cost will be approximately $9 per acre-foot per year using Reclamation's 2004 fiscal year plan formulation interest rate of 4.8934 percent and assuming a 50 year replacement life cycle.

The last column in Table 2 is labeled "Total Potential Benefit to the 15-Mile Reach" because of the nature of the legal protection mechanism employed to protect Project conserved water. Only the stored water component of the reduced diversions has the potential to be legally protected if they result in a surplus storage condition in Green Mountain Reservoir.

In 2002 the HUP never achieved a fill and actual storage conditions never exceeded the surplus storage criteria because of the severity of the drought. Therefore no surplus water was delivered to benefit endangered fish habitat. However, without the Project facilities and the ability they provide to manage irrigation diversions, the HUP would have been exhausted by mid August of 2002 with disastrous results for West slope irrigators and municipalities.

In 2003 Green Mountain Reservoir HUP storage levels resulted in the declaration of a surplus storage condition in late August. As a result 47,526 acre-feet of Green Mountain HUP water was released and legally protected to benefit endangered fish habitat. This magnitude of surplus water could not have been achieved without operation of Project facilities and the resulting 32,916 acre-feet of reduced diversions.

FUTURE APPLICATIONS

The Highline Canal serves approximately 50 percent of the lands in the Grand Valley that are irrigated by diversions from the Colorado River. Similar opportunities to conserve water by increasing irrigation delivery efficiencies are possible from the other canal systems with potentially very attractive unit costs. Because of their geographic location and relative water right priority within the State appropriation system, conserved water could be redirected for environmental and/or human uses on both the West and East slopes without injury to other appropriators. This concept is equally applicable to any river system if the appropriate environmental protections and institutional agreements can be developed to capitalize on technical advances in water use efficiency.

SALT LAKE VALLEY WATER SUPPLY CURRENT EVENTS A PERSPECTIVE FROM THE METROPOLITAN WATER DISTRICT OF SALT LAKE & SANDY

Michael L. Wilson[1]

ABSTRACT

The purpose of this paper is to provide insight to the extensive coordination and cooperation of the Metropolitan Water District of Salt Lake & Sandy ("Metro"), its member cities, and other partnering agencies related to ongoing matters related to water supplies to the Salt Lake Valley, Utah.

Planning over the last several years has lead to the implementation of several major capital improvement projects designed to enhance the water infrastructure in the Salt Lake Valley. Established in 1935, Metro provides water service to an estimated 400,000 people within the Salt Lake Valley. As indicated by the name of the District, the primary customers of Metro are its member cities, Salt Lake City and Sandy City. In addition, Metro coordinates water supply and conveyance needs on a surplus basis with the other major water wholesaler in the Salt Lake Valley, the Jordan Valley Water Conservancy District ("Jordan Valley").

Master planning efforts that began in 1996 have culminated in the ongoing design and construction of more than $200 million in water system improvements by Metro. Key projects include the Point of the Mountain Water Treatment Plant and the Point of the Mountain Aqueduct. These key improvements will accomplish their purpose of meeting the future needs of Salt Lake City and Sandy City. In addition, the improvements will combine with existing infrastructure to provide valley-wide system redundancy on an unprecedented scale. These projects are scheduled to be completed on or before June 1, 2007.

Other major efforts currently being pursued include the proposed enclosure of the Provo Reservoir Canal and Title Transfer of Provo River Project facilities to local sponsors of the Provo River Project.

BACKGROUND

Agency Relationships

The Provo River Project ("PRP") was planned and implemented during the 1930s and 1940s by the United States Bureau of Reclamation ("BOR"). The project

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consisted of two divisions: the Deer Creek division and the Salt Lake Aqueduct division. Two entities were created to act as local sponsors for this project. The Provo River Water Users Association ("Association") was established in 1935 to oversee the operation and maintenance of the Deer Creek division of the PRP. The Metropolitan Water District of Salt Lake & Sandy ("Metro") was established in 1935 to oversee the operation and maintenance of the Salt Lake Aqueduct division of the PRP. In addition to its direct involvement in the Salt Lake Aqueduct, Metro currently owns 61.7% of the stock of the Association. The water supply represented by this stock ownership constitutes a major portion of the water supply that has allowed the Salt Lake Valley to grow and prosper during the last eight decades.

Metro serves its two member cities, Salt Lake City and Sandy City. In 1951, the Jordan Valley Water Conservancy District ("Jordan Valley") was established. Jordan Valley currently serves the bulk of the areas of Salt Lake Valley outside of Salt Lake and Sandy. Jordan Valley has obtained an interest in the Association via share ownership in the Provo Reservoir Water Users Company ("the Company") which owns 16% of the stock of the Association and other water supplies from the Provo River.

Both Metro and Jordan Valley receive water supplies from the Central Utah Water Conservancy District ("Central Utah"). Central Utah, established in 1965, is currently completing the Central Utah Project ("CUP") which will provide additional water supplies to several areas in northern and central Utah including the Salt Lake Valley.

Existing Infrastructure

A brief description of some of the key infrastructure systems that provide water to the Salt Lake Valley is provided below. See Figure 1 for a map showing these facilities.

Provo Reservoir Canal ("the PRC"): This facility was constructed in the early 1900s. As part of the PRP, the PRC was purchased by the BOR and upgraded to its current condition. Most of the shareholders of the Association have capacity rights in the PRC. Historically, the PRC has delivered agricultural water supplies to northern Utah County and Salt Lake County. As these areas become increasingly urbanized, the PRC is being utilized to convey water for municipal and industrial purposes. Currently, both Metro and JVWCD have capacity rights in the PRC. Jordan Valley's capacity is by virtue of its stock ownership in the Company. This facility is owned by the BOR and operated and maintained by the Association.

Salt Lake Aqueduct: This facility was constructed during the 1930s and 1940s

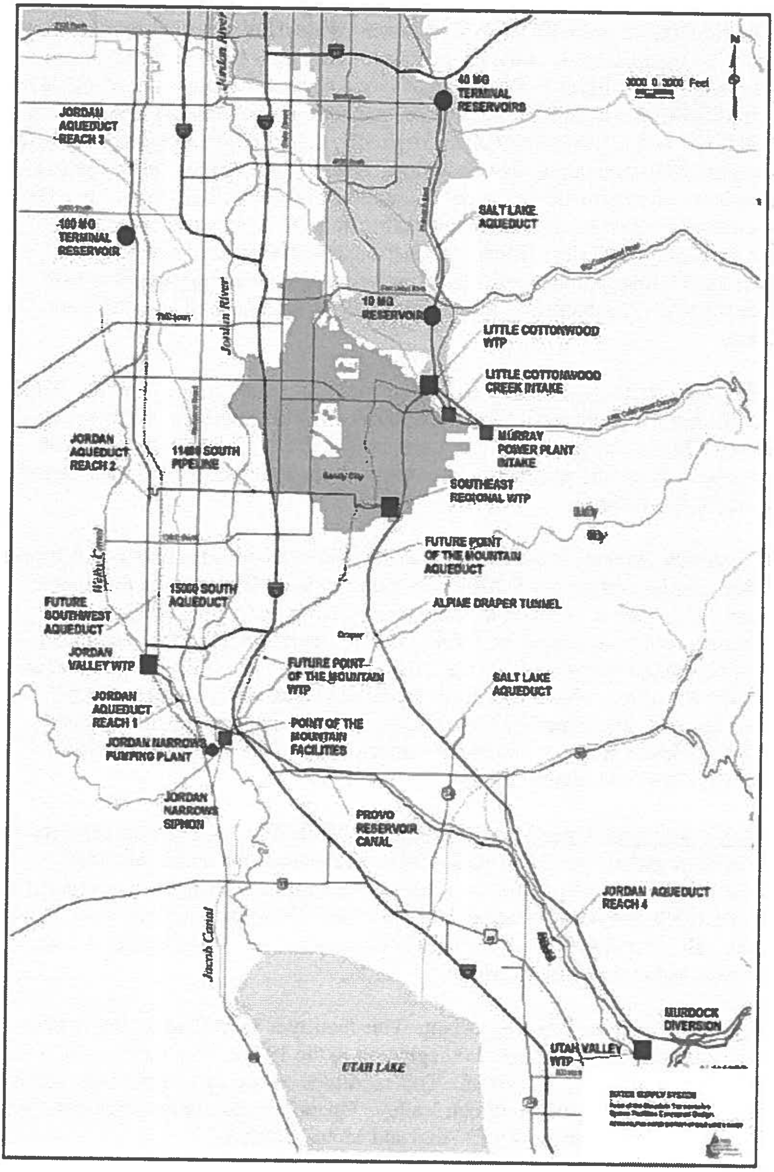

Figure 1. Existing Infrastructure

and was finally made operational in 1951. The aqueduct consists of approximately 42 miles of primarily 69-inch inside diameter reinforced concrete pipe. The pipeline starts at the base of Deer Creek dam in Provo Canyon and follows the Provo River to the mouth of Provo Canyon, continues north along the foothills of Utah and Salt Lake counties, and ends at the Terminal Reservoirs near 3300 South and I-215 in Salt Lake. Originally, the Salt Lake Aqueduct conveyed untreated PRP water along its entire route. The primary purpose of the Salt Lake Aqueduct was to provide municipal and industrial water to Salt Lake City. This was one of the first facilities constructed by the BOR to serve a purpose other than irrigation deliveries. Today, the Salt Lake Aqueduct conveys untreated water for 33 miles and delivers treated water along a nine mile stretch in Salt Lake County. This facility is owned by the BOR and operated and maintained by Metro.

<u>Jordan Aqueduct</u>: This facility was constructed as part of the CUP in the 1970s. The 78-inch inside diameter pipeline delivers water from the Provo River near the mouth of Provo Canyon to the Salt Lake Valley. The pipeline ends near 2100 South 3200 West and primarily serves the western and northwestern portions of the Salt Lake Valley.

The capacity interests in the Jordan Aqueduct are split between Metro and Jordan Valley. Jordan Valley has 5/7ths of the capacity and Metro has the remaining 2/7ths. This ratio is based on the amount of CUP water supply that has been petitioned for by each agency. Jordan Valley is currently receiving an annual supply of 50,000 acre-feet from the CUP. Metro will ultimately take 20,000 acre-feet of CUP water. Metro will begin taking deliveries of CUP water in 2005. These facilities are owned by Central Utah and are operated and maintained by Jordan Valley. Operation and maintenance costs are shared between Jordan Valley (5/7ths) and Metro (2/7ths).

<u>Little Cottonwood Water Treatment Plant</u>: This facility has a current capacity of 113 million gallons per day (MGD) and is located near the mouth of Little Cottonwood Canyon in Salt Lake Valley. The treatment plant was constructed in the late 1950s and began treating water in 1960. The treatment plant is supplied by the Salt Lake Aqueduct and Little Cottonwood Creek. This facility is owned, operated, and maintained by Metro.

<u>Jordan Valley Water Treatment Plant</u>: This facility is located in southern Salt Lake County and was constructed beginning in the 1970s. It is supplied by water from the Jordan Aqueduct system. This facility is owned by Central Utah and is operated and maintained by Jordan Valley. Operation and maintenance costs are shared between Jordan Valley (5/7ths) and Metro (2/7ths).

<u>Southeast Regional Water Treatment Plant</u>: This facility is owned and operated by Jordan Valley. Constructed in 1980s, it is located in the southeast part of Salt

Lake County. Water treated at this location is supplied by five mountain streams immediately south of Little Cottonwood Canyon along the Wasatch Front and by the Salt Lake Aqueduct.

15000 South Pipeline: This pipeline was constructed in the late 1990s by Jordan Valley and Metro. Each agency has a 50% capacity and ownership interest in the facility. The 48-inch inside diameter pipeline has a capacity of 51 MGD.

MASTER PLANNING

In 1996, Metro's member cities, Salt Lake City and Sandy City, completed updates to their water system master plans. These master planning efforts identified the needs of each member city. In addition to forecasting water supply needs, the studies identified the long term needs in terms of water system conveyance capacity.

Based on the cities' master plans Metro began an evaluation of alternatives to meet the needs. Metro had not conducted a master planning exercise since 1984. Many items of the older master plan had already been implemented. However, there were some items that were yet to be accomplished. In 1984, Metro was a single-city District with Salt Lake City being the sole member. Sandy City was annexed into the district in 1990. The new master planning effort was charged with taking into account the needs of both cities. Metro's master plan update was completed in 1998.

The 1998 Master Plan Update evaluated as many as 22 separate alternatives to achieve the desired result of meeting the cities needs. At the completion of this evaluation, three preferred alternatives were identified. The three preferred alternatives were evaluated in more detail in a study known as the Further Evaluation Study. The final result of the master planning efforts was a recommendation to construct a new treatment facility near the "Point of the Mountain" near the Utah County-Salt Lake County line. The source of supply for the new treatment plant would be the PRC. The new 70 MGD treatment plant will enhance the system capacity of Metro.

In addition, the recommendation included a new aqueduct to convey water from the new treatment plant to the existing Little Cottonwood Water Treatment Plant. The 12-mile long, 60-inch diameter aqueduct will be routed through Draper City and Sandy City. The new facilities to be constructed by Metro are shown in Figure 2.

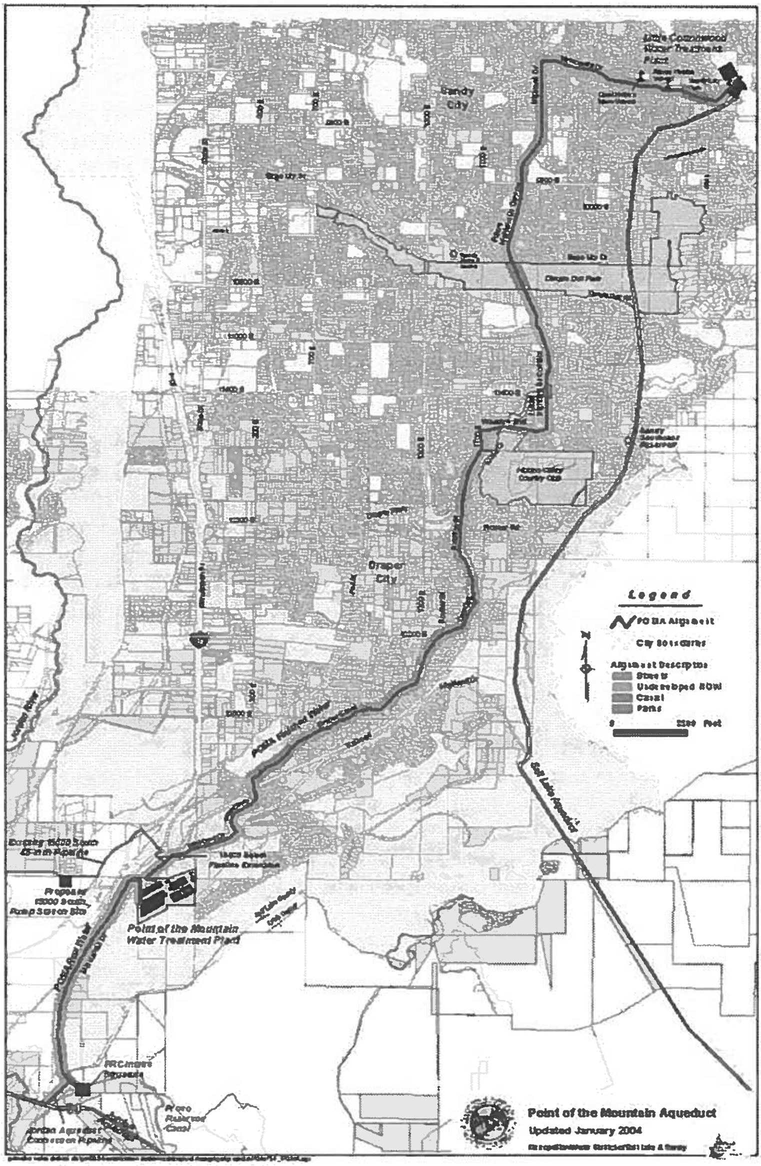

Figure 2. Metro Master Plan Facilities

COOPERATIVE AGREEMENTS

Concurrent with the master planning activities, Metro, Salt Lake City, and Sandy City negotiated a cooperative agreement that provided for the scope, financing, scheduling, and operations of the proposed master plan improvements. This agreement is commonly referred to as the "Metro Member Cities Interlocal Agreement" and was finalized in 2001. The agreement identified facilities that developed new system capacity as "Capacity Capital Improvements." Projects that were upgrades or rehabilitation projects were called "Non-capacity Improvements." In effect, new facilities are to be paid for based on the new capacity developed for a particular agency as part of the new construction. Projects that deal with existing facilities will be paid for out of traditional revenues of the district (water sales and property taxes). This approach has come to be known as the "pay for what you get approach."

In addition to the Cities Interlocal Agreement, Metro and Jordan Valley are finalizing an agreement that will lead to unprecedented cooperation between the two agencies. With the construction of the Point of the Mountain Facilities, the infrastructure system in the Salt Lake Valley will be interconnected in a manner that will allow for greater system redundancy and better utilization of available water resources. The Metro-Jordan Valley agreement addresses participation in the construction of various facilities, shared system capacities, and shared water supplies. This agreement will define the relationship of the two major water Districts in the Salt Lake Valley for years to come.

TITLE TRANSFER

Other projects of interest that Metro and others are involved in include the proposed Title Transfer (from the Bureau of Reclamation) of the Salt Lake Aqueduct and the PRC, the enclosure or piping of the PRC, and the Utah Lake System ("ULS") component of the CUP.

The PRC Enclosure Project has been contemplated for several years. The existing canal is an open canal that has historically been in an agricultural setting. As the area that the canal traverses becomes increasingly urbanized, concerns related to public safety, water quality, capacity restrictions, and future demands has led to the need for the PRC to be enclosed. The scope of the project is estimated to be a $115 million effort to pipe or otherwise enclose the canal. An Environmental Assessment related to the enclosure has been completed. Current efforts related to the enclosure project relate to coordinating with various entities to finalize the financing and participation in the project.

The ULS is one of the last components of the Bonneville Unit of the CUP to be designed and constructed. The ULS is anticipated to supply approximately 30,000 acre-feet of water to the Salt Lake Valley via a new delivery system from the mouth of Spanish Fork Canyon located in southern Utah County. Key to this delivery system is the proposed use of the PRC to convey water north to Salt Lake County. Specifically, the ULS project would utilize canal capacity earmarked for Metro and Jordan Valley plus 50 cfs of canal capacity earmarked for Central Utah to convey the water supply to the north.

As mentioned above, the PRC and Salt Lake Aqueduct are existing facilities that are features of the PRP that was conceived in the 1930s. The proposed transfer would result in the title to the Salt Lake Aqueduct being in the name of Metro. The PRC would be transferred to the Association and/or a proposed Joint Public Agency. Title Transfer is a process that allows for federal facilities to be transferred to local interests as long as certain conditions are met. The process requires congressional action in order to facilitate the transfer. Several agencies are coordinating to make the Title Transfer a reality.

The Title Transfer is spurred by the inability of the Association to obtain tax-exempt financing for the PRC Enclosure Project. This is due to the fact that the Association is a private entity and that the PRC is a facility owned by the federal government. Nearly 85% of the stock ownership of the Association is held by public agencies. These agencies are able to obtain tax-exempt financing for the project. However, to be put in position to obtain this type of financing, the facility needs to be transferred from federal ownership.

For similar reasons the Salt Lake Aqueduct is included in the Title Transfer effort. The aqueduct and related facilities are more than 50 years old. Studies indicate that the aqueduct is in excellent shape for a facility of its age. However, the same studies indicate that rehabilitation or replacement of certain facilities will be needed beginning as early as 2010 with the proposed replacement of the terminal reservoirs (40 million gallons). Again, in order to obtain tax-exempt financing, Metro is pursuing the transfer of title from the federal government to Metro.

Central Utah, as part of the ULS project, has offered to pay for half of the cost to enclose the PRC. As a public agency, Central Utah has the ability to obtain tax-exempt financing for their portion of the project. In order for all of the involved agencies to meet the multiple objectives described above, the agencies are working together to coordinate the Title Transfer, enclosure of the PRC, and the successful completion of the ULS project.

CONCLUSION

This paper has tried to provide an update to the ongoing activities of water supply matters affecting the Salt Lake Valley from the perspective of Metro. Other agencies have embarked on several other projects. All of these efforts are needed to meet the needs of an area that is rapidly urbanizing.

Metro is actively pursuing its master plan projects. These are exciting times for Metro. Since the early 1960s, Metro has been an agency that has performed operations and maintenance of its facilities. The efforts to construct the master plan facilities are a tremendous load for the district staff and its team of consultants. However, all involved recognize the importance of developing facilities to meet the future needs of Metro's member cities and the entire Salt Lake Valley.

ON-LINE AND REAL-TIME WATER RIGHT ALLOCATION IN UTAH'S SEVIER RIVER BASIN

Wynn R. Walker[1]
Roger D. Hansen[2]

ABSTRACT

The Sevier River Basin in central Utah is one of the state's most critically water-short areas. The Bureau of Reclamation and Utah State University have had a long-term partnership with the Sevier River Water Users Association to automate the river and implement real-time water right allocations. The Bureau has now automated nearly all of the key canal, reservoir, and stream gauging stations along the main stem of the river. Utah State University has implemented the water rights allocation procedures. Both efforts have substantially assisted the River Commissioners in the day to day regulation of the river. For the users, this system has reduce the information time lag from about 45 days to a single day, thereby allowing them a substantially greater water management capability.

HISTORICAL CONTEXT

Utah's pioneers understood the need for irrigation and were aware of its rudiments long before their initial entry to the Salt Lake Valley in July 1847. It is therefore not surprising that these pioneers diverted water from City Creek the day after their arrival. What is surprising are the ways water rights evolved over the next half century to accommodate water management needs in an arid environment. Substantial innovation and adaptation were necessary to avoid severe economic loss and community conflict. The water rights of the Sevier River Basin in central Utah (Figure 1) are among the most imaginative and effective of these adaptations.

The early settlement of the Sevier River Basin began in 1849. However, irrigation development was effectively halted in the 1850's and 1860's by the Walker and Black Hawk Indian wars. When the Black Hawk War was concluded in 1868, settlement and irrigation development resumed in earnest, and simultaneously, from Panguitch in the headwaters to Delta at the mouth of the river.

The early irrigation developments were interesting. Most were located on tributary streams where the relatively high gradient and rocky bottoms allowed the irrigators to divert water by simple rock and brush dams into short right or left bank ditches. Where the settlers were forced to divert the river itself, the

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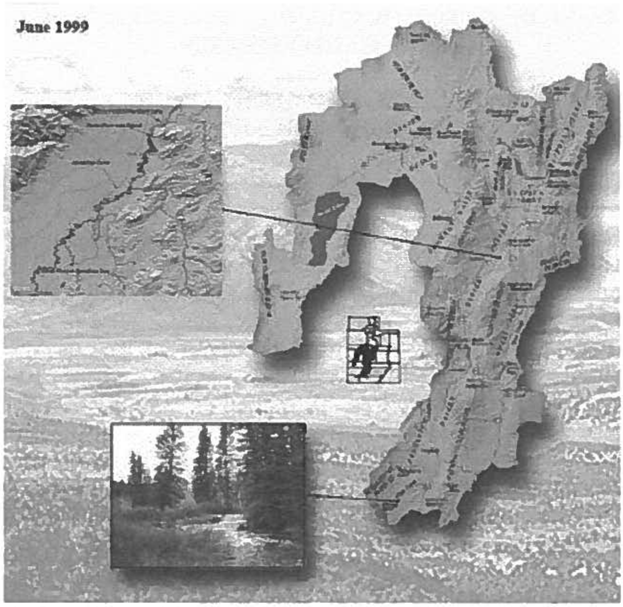

Figure 1. Location and Setting of Utah's Sevier River Basin. (Source: State Water Plan, Sevier River Basin, Utah Board of Water Resources, June 1999)

makeshift dams were easily destroyed during the high runoff periods. For instance, what is now Gunnison Bend Reservoir near Delta is the result of nine failures between 1860 and 1983.

The struggles to stabilize a water supply have had significant effects on the structure of local water rights. No central civil authority existed during the first 30 years of these developments to resolve conflict, allocate water during shortages, or coordinate water uses. However, since the developments were small and the runoff adequate, there were few such needs until the drought years of the 1890's. And, at about the same time, nearly all arable land that could be supplied water by these small direct diversions had been developed. Plans were moving ahead rapidly to expand irrigation by constructing reservoirs to capture high, unused flows and winter water. Interestingly, the lands already developed were sufficient to utilize nearly all of the water in the dry years. In fact, in the late 1890's there was a period when no water reached the town of Deseret at the end of the river and litigation began in earnest. By 1903 when Utah had enacted its major water law, the Sevier River was still critically short of water, and more than 40 lawsuits were in progress to establish water rights.

PRIMARY RIGHTS

Two institutional distinctions emerged by the 1890's which defined early water rights. The first is that while water management was primarily treated as small community enterprises, the communities along the river had essentially formed two camps, the "upper basin" and the "lower basin". As water rights were perfected, this division point became the river gauging station immediately below the canal diversion to the Vermillion Canal Company. This point is called Vermillion Dam and will be noted again later.

As the law suits noted above were settled, two major river decrees were issued. The first was the Higgins Decree of 1901 covering the lower river and the second was the Morse Decree of 1906, covering the upper. Both decrees delineated the rights of various users to directly divert and use the flows of streams or the river as they flow past their point of diversion. These are called "primary" rights. The aggregate flows consisting of groundwater inflows, tributary inflows, and irrigation return flows within a reach are called "the primary".

The Appropriation Doctrine of "first in time, first in right" governed the development of Sevier River water rights. However, most of the rights diverting directly from the river or its tributaries initiated prior to formal government structure and the interruption of development due to the Indian wars produced almost simultaneous water development all along the river. Thus, the courts could not firmly establish priorities in time. Instead, the Higgins Decree adopted the unusual approach of setting nearly all of the direct flow rights below Vermillion Dam on a common priority. It also recognized some rights were clearly aimed at high water flows so it defined several "classes" of right. In effect, the decree recognized essentially the maximum claim of each user.

The Higgins Decree added one more interesting feature by requiring that whenever the supply of water was insufficient to meet all of the rights within a class, that these rights would each prorate the flow and thereby share equally in the shortage. When water was available above the flows of a given class, it was allocated to the next class with the same prorating feature. The class priorities are based on what was considered a basic supply and then on succeeding levels of surplus. In other words, the Higgins Decree allocated the river below Vermillion Dam on the basis of supply frequency and need. These features were adopted in form in the later Morse Decree with different definitions of right classes. For instance, the classes in the lower basin are called A, B, C, D, E, and F rights whereas in the upper basin they are called first , second , and third class rights.

Neither the Higgins Decree nor the Morse Decree dealt with the rights to water for storage and neither dealt with the allocation of water between the two river zones. Further, neither included resources for personnel to measure and regulate flows. They were thus generally ignored during periods of low flow. Nevertheless, the critical concepts of staged class and prorating shortages were established and the quantitative needs of each water user were outlined. In later litigation when a more general water right system was defined, the primary rights defined by the Higgins and Morse Decrees were essentially adopted in total.

STORAGE RIGHTS

Primary rights are defined by discharge at a specific place and time, and ultimately by the day to day needs of the area they are applied to. Water in excess of these requirements is appropriated to various storage rights and accumulates in the reservoirs of the Sevier River. The users in the river system had been aware for many years that substantial water was escaping during the high flow periods of May and June and throughout the winter months. Another source of "excess" water available for the storage rights was the unused primary flows.

Gunnison Bend Reservoir at the end of the river had been built and destroyed since the 1860's with the structure in use today being finalized in 1895. In 1897 construction of Otter Creek Reservoir was initiated followed by Sevier Bridge in 1902. These reservoirs had the capacity to store all excess water during a typical "dry' year, but in 1906 and 1907 the water supply was relative large and plans were made to enlarge Sevier Bridge and construct Piute Reservoir. Piute Reservoir was completed in 1908 and the Sevier Bride enlargement was completed in 1918. With the construction of these reservoirs came major developments for literally hundreds of thousands of new acres.

When the inevitable dry cycle returned so did the lawsuits over water rights. The river was defined by two water decrees neither of which were reconciled with each other and neither or which resolved the question of where the primary rights ended and the storage rights began. In 1925, the Utah State Engineer used one lawsuit as a vehicle to adjudicate the entire river system. Local and regional committees of water users were formed to negotiate and stipulate water rights because the costs of resolutions in the courts were too high and unpredictable. Amazingly, they succeeded after nine years and their agreement was adopted by the courts as the Cox Decree. In addition to almost verbatim inclusion of the Higgins and Morse Decrees, the Cox Decree linked the two halves together and defined the relationship between the primary and storage rights. A number of lawsuits have ensured to refine, clarify, or correct the Cox Decree, but it remains today as the Sevier River's fundamental water right instrument.

Perhaps as important as the allocations of the Sevier River flows were the provisions for two "River Commissioners" to monitor and regulate the river through a series of river gauging stations and monitored flows into each canal. Specifically, the Commissioners were charged with implementing the Cox Decree and collecting sufficient data to do so accurately. Funds for their salary and expenses come from all the users of the Sevier River, but they reported directly to the Utah State Engineer. Hence, the data acquisition and control functions performed by the Commissioners are in effect the basis of water management in the Sevier River Basin.

HISTORIC DATA ACQUISTION AND CONTROL

The Cox Decree defined all the water rights in the Sevier River system, but the interpretation of such by the Commissioners is the reality of the rights. Procedures were devised to quantify each right using the stream, reservoir, and canal diversion measurements. Most gauging stations were eventually equipped with stage recorders and measurements by the commissioners formed the basis for local calibrations. The timeframe chosen for accounting each right was one day, but the records were collected and "worked" each month.

It is easy to imagine the operational problems of administering daily rights on a monthly interval. The users didn't know of their rights until a month or more later and were continually over-diverting in violation of their rights or under-diverting at the expense of their irrigated acreage. The Commissioners and the users devised a number of practical remedies by which the primary users would be allowed temporary storage in the reservoirs. In some cases they were allowed to "over-draft" their rights from the reservoir rights for short periods. A short case study here will demonstrate the concepts of Sevier River water rights and their management.

The Rocky Ford/Willow Bend Case Study

The Rocky Ford Canal Company and the Willow Bend Irrigation Company jointly divert water from the main stem of the Sevier River just below Vermillion Dam. (See Figure 1 for its general location and Figure 2 below for an enlarged view.) The rights of these users are defined as all the irrigation return flows, groundwater inflows, and tributary inflows to the Sevier River between Vermillion Dam and the Rocky Ford Reservoir Dam. The right has an upper limit of 24,000 acre-feet during the April 1 to October 15 period of each year. In addition, the two companies are entitled to fill their reservoir with up to 2,000 acre-feet of the accumulated flow in the reach during the month of March, but they do not have an irrigation right until April 1. This water is charged against their maximum right of 24,000 acre-feet and is also limited for use to the April 1 - October 15th period.

All flows escaping the upper basin or being transferred to the lower basin as recorded at Vermillion Dam are allocated to the storage rights. Thus commencing March 1st, the flow passing over Vermillion Dam must be delivered through Rocky Ford Reservoir into Sevier Bridge Reservoir as a right segregated from any of the primary flows that may be used by the Rocky Ford/Willow Bend right. Based on many years of experience, the Commissioners and the users have agreed that any flow over Vermillion Dam would experience a loss of 2% through this section of river.

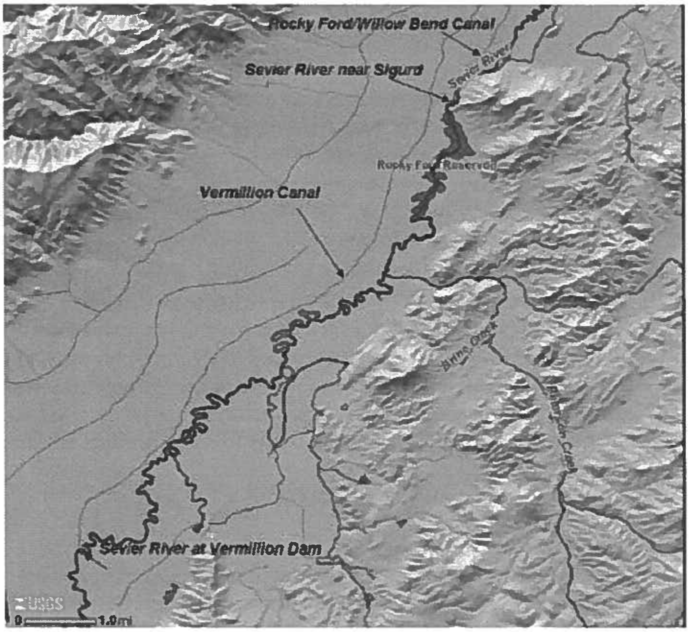

Figure 2. Location and Setting of the Rocky Ford/Willow Bend System. (Source USGS)

Since the records and computations of the Rocky Ford/Willow Bend right lag actual daily used by as much as a month, these users have had no effective way to determine and then divert their right. Working with the Commissioners, an agreement has been reached in which these users are allowed to overdraft their right so long as the overdraft is made up by October 1st. In other words, they are able under this agreement to overdraft during the high demand periods of July and August and repay the overdraft when the demand is low in September. The effect is to increase the irrigated acreage under this right, and as such, use more water than the right was allowed by decree.

None of these management features are outlined in the river decrees. Clearly the right has been enlarged beyond it original intent to accommodate the needs of the Commissioners to manage the water effectively. This is a common problem faced by those trying to implement a legal description in a physical setting and many special arrangements are implemented to accommodate the day to day reality of water management in the field.

ON-LINE, REAL-TIME DATA ACQUISITION AND CONTROL

Today, all of the river, canal, and reservoir stations used by the commissioners to determine and allocate Sevier River water rights along the main stem are equipped with electronic sensors and telemetry systems. Data are record at hourly and daily intervals, transmitted to computers and published on the Internet. Each day, the data are also transmitted to USU where software computes and allocates the water rights. This information is also available on the Internet.

In addition to the data acquisition systems, many of the reservoir and canal controls are connected to the same telemetry system but not to the Internet for security reasons. Consequently, the River Commissioners now have access to instantaneous flows and water levels, daily estimates of individual water rights, and instantaneous capability to remotely control key system structures. A detailed summary of the development and nature of this system is provided by Sevier River Water Users, et al. (2004)[3].

The transition from the historical monthly based management system to today's hourly and daily system occurred over the period of 1991 to 2004. Beginning with the automation of canal and reservoir gates and eventually reaching a system status involving a number to equipment and software innovations.

SIMULATING THE WATER RIGHT ALLOCATION PROCESS

Beginning in 1975 and continuing through 2003, an effort was made to simulate the processes used by the Commissioners to define and allocation primary and storage rights along the main stem of the river. This evolved three components: (1) segregation of total primary and storage flows in the system; (2) allocating primary and storage to individual rights; and (3) developing right by right accounting mechanisms.

Computing Primary and Storage Flows

Primary is comprised of irrigation return flows, groundwater inflows, and tributary inflows. It does not include water bypassed in an upstream section because of non-use. For instance, the primary in the lower zone is comprised of primary "make" along the river between the Vermillion Dam and the end of the river at Delta. Figure 3 shows the total primary for the month of June 1970.

The primary calculations are of a single type – ***outflow-inflow = primary***. There are two special provisions in the Cox Decree that bear on the primary computations. The first is that since primary flows were being used before the reservoirs were built, there were some primary flows that were available within the reaches that were later inundated. With the reservoir construction, these flows

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[3] Sevier River Water Users, StoneFly Technology, Inc., Utah State University, and U.S. Bureau of Reclamation. (2004). Sevier River Basin Water Resource Management Network: Evolving Toward Sentience. Final Report to the Department of Commerce's Technology Opportunity Program.

could no longer be identified and were "stipulated" in the decree as fixed amounts based on average estimates prior to the reservoirs.

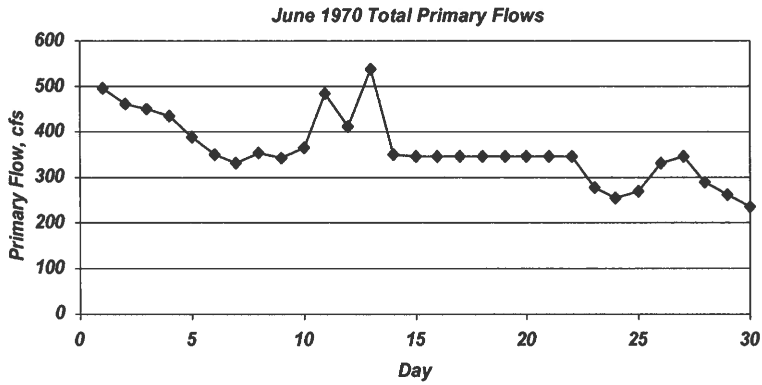

Figure 3.

The second special provision the decree imposed was that primary flows occur without diminution. In other words, all steam losses are charged to storage flows. Thus, storage flows must be determined day by day just as primary flows are to account for stream losses. Otherwise, storage rights could be simply determined by monthly water balances of the systems' reservoirs.

Daily Water Rights Allocation and Accounting

Detailed water rights in the Sevier River systems are modeled by a software package called ***SEVIER III***. The various algorithms have been verified and are now in use by the River Commissioners. Real-time data from river, canal, and reservoir gauging stations are now automatically loaded to a server at midnight of each 24 hour period and then processed by the ***SEVIER III*** software to provide real-time information to the varied individual rights. The accounting system for each right shows the accrual of the rights as well as the use and balances for each major user.

Figure 4 shows the allocation of the primary shown in Figure 3 among the primary right classes in the lower river zone. This figure allows any user or manager to determine what components of the overall rights are accruing at any point in time. This information is then allocated to each right holder as illustrated in Figure 5. As a result of the real time capabilities in the Sevier River Basin and the data processing capabilities, the entire river system is now operated much like a commercial bank, in this case a water bank.

DISCUSSION

Water rights in the Sevier River Basin which have been determined on a daily basis but managed monthly are now managed hourly and daily thanks to system-wide application of SCADA technology and water right allocation software. The monitoring system allows every user a view of the water flows and reservoir storage, thereby presenting a holistic picture of water management in the basin. Conflicts that have historically resulted in over diversion can now be remedied as day today enforcement of right limitations can now be made.

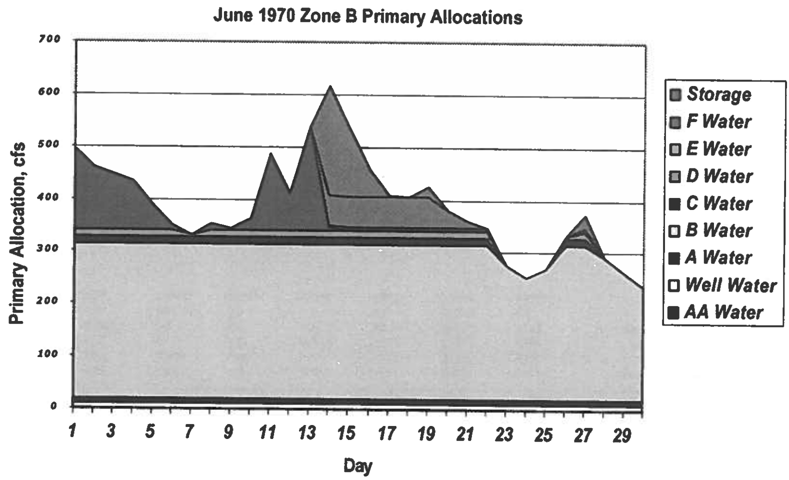

Figure 4.

The new system has a number of features that will be invaluable in coming years. The flooding of 1983 and 1984 when the river could not be controlled as a unit, with the consequent loss of two reservoirs, will now be a thing of the past. Water management is being improved as less and less water is by-passed in the system resulting in a more stable water supply throughout the system. In short, the implementation of advance monitoring, control, and water right software has raised water management in the Sevier River Basin in an entirely new level.

Exit Print Year 1970 Holdings, af 3500

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Beginning Credits, af	9500.0	21298.8	22715.1	24534.4	23059.0	21480.0	21981.3	1284.0
Primary Credits, af								
AA + Wells, af	0.0	357.0	368.9	357.0	368.9	368.9	357.0	0.0
A Water, af	3531.9	2783.2	3488.9	3395.4	2499.9	2691.1	2896.7	0.0
B Water, af	268.8	37.3	244.6	238.0	0.0	0.0	0.0	0.0
C Water, af	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D Water, af	0.0	48.1	3399.2	838.3	0.0	0.0	0.0	0.0
E Water, af	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F Water, af	380.9	0.0	0.0	129.3	0.0	0.0	0.0	0.0
Total Primary	4180.6	3225.6	7493.6	4958.1	2868.8	3060.0	3253.8	0.0
New Storage Credits, af								
1st Increment (184,000)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2nd Increment (132,000)	6980.6	253.2	180.4	191.0	79.3	60.0	102.2	0.0
3rd Increment (>236,000)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exchange Water	0.0	0.0	0.0	0.0	29.8	9.5	10.1	0.0
Winter Water	3595.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DMAD Wells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transfers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Storage	10676.5	253.2	180.4	191.0	109.1	69.4	112.3	0.0
Uses and Losses, af								
Canal Diversions	1311.1	1570.3	5311.0	5132.5	4047.8	3165.7	799.8	751.8
IPA Diversions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sevier Bridge Losses	670.1	0.0	0.0	0.0	0.0	0.0	23094.8	0.0
River Transit Losses	251.8	50.5	795.5	1030.0	62.7	173.5	82.9	2.9
DMAD Losses	377.9	292.6	-242.1	417.6	186.5	-676.7	165.7	-240.4
Gunnison Bend Losses	446.5	149.0	-30.4	99.2	-9.1	-65.2	-70.1	-122.6
Total Use & Losses	3057.4	2062.5	5794.8	6684.4	4587.9	2597.2	24063.3	392.8
Ending Credits, af	21298.8	22795.1	24534.4	23059.0	23140.8	21981.3	1284.0	901.2

Figure 5. Typical water right account for a "storage" right in the Servier River Basin

IMPROVING EQUITY OF WATER DISTRIBUTION: THE CHALLENGE FOR FARMER ORGANIZATIONS IN SINDH, PAKISTAN.

Bakhshal Lashari[1]
Yameen Memon[2]
Hammond Murray-Rust[3]

ABSTRACT

A major objective of the Pilot Project for Farmer-Managed Irrigation in Sindh has been to help Farmer Organizations (FOs) achieve greater equity of water distribution. By giving full responsibility to water users for both operations and maintenance it is hoped that they will be able to develop water sharing mechanisms that reflect their views of equity rather than have a standardized view of equity imposed upon them by outside authorities.

Two elements of equity are considered on the basis of the results collected in the pre-transfer period. External equity issues look at water allocation and delivery between different distributaries. The three sample canals show wide variations in water deliveries, ranging from just under 100% of design to almost 200%.

Internal equity issues look at how water is shared between watercourses along a canal. In the two canals with favorable water deliveries at the head there is no noticeable head-tail difference, and all farmers get at least design discharge during the peak of the summer season. The third canal which gets close to design discharge shows a marked disparity between head and tail, with tail enders more or less deprived of reliable water.

To help farmers improve internal equity canals have been divided into three reaches more or less equivalent to head, middle and tail sections. Gauges established at each boundary provide farmers with a simple tool to determine whether each reach is taking more or less of its fair share of water. An accompanying table provides water level targets that the Farmer Organization can use as operational guidelines to allocate water between the different sections of the canal.

The farmer organizations in the three canals have become constrained because they still do not have legal powers to allocate and distribute water between watercourses, nor to determine the size of outlet structures to watercourses. If the

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enabling legislation is further delayed then it is likely the organizations will wither and become ineffective.

BACKGROUND

The decision of the Government of Pakistan to establish the Provincial Irrigation and Drainage Authorities carried with the policy of transfer of operation and maintenance responsibility from government to water users at secondary level. Traditionally water users have always had Operation and Maintenance (O&M) responsibility at watercourse (tertiary) level, although tertiary level operations are often guided by the time-sharing system known as warabandi that allows little or no flexibility in determining whose turn it is to receive water.

The increased responsibility for water users does not represent a simple increase in the amount of day to day management they already undertake. It involves a range of activities normally the preserve of government, it gets water users involved in making water allocation decisions at secondary level, in hiring staff and equipment to assist in operation and maintenance procedures, in collection of water fees and decisions about how to spend their share of money to meet the objectives of the association, and it involves direct interaction with officials of the newly established Area Water Boards which cover several secondary canals.

This paper focuses on only one aspect of the challenges facing the newly established secondary level organizations, namely the establishment of improved equity. It is based on experiences gained in assisting the process of organization of farmers on three secondary canals in Sindh which includes a detailed monitoring program that can assess the overall performance of organizations after they have been given full legal rights to manage their canals independently of government.

Concepts of Equity and Equality

The original design of irrigation canals in Sindh was based firmly on the concept of water rationing, sometimes referred to as protective irrigation. Water was allocated on a per-acre basis at a level insufficient for a farmer to irrigate all of his land holding so that cropping intensities could not reach 200%. In the canals selected for organization in the Pilot Project the design annual cropping intensity is approximately 100%, so that at any given time roughly half the land is expected to remain fallow.

To accomplish these design objectives the water delivery program was designed to meet strict discharge targets at all levels of the system. Starting at the watercourse level the design discharge can be determined using the concept of duty (traditionally expressed in cusecs per 1000 acres). The control structure at the head of each watercourse is then constructed so that the orifice or flume in the structure will deliver the precise discharge as long as the secondary canal water level is at designed elevation. There are no operable components in the outlet structure.

The watercourse discharges are then cumulated to determine the discharge at the head of the secondary canal plus an allowance for estimated losses within the secondary canal. Typically a value of 20% losses at secondary level is assumed. The same process is repeated in main canals, where secondary canal discharges are cumulated and an additional 10% added to allow for discharge. Under normal operating conditions, therefore, the intended discharge at each location in the system should be known. If, the intended plan is properly implemented then there will be close to perfect equality in water distribution. From the perspective of a secondary canal level farmer organization there are two different types of equity that they must try to deal with:

External Equity refers to the relative share of water the secondary canal receives compared with the discharges delivered to other secondary canals along the same main canal, while

Internal Equity refers to the sharing of water between different watercourses along the secondary.

DATA COLLECTION

The data collection was made from 1996 to 1998 which covered three secondary canals, however the project area was extended for other ten secondary canals. The results are discussed on only three secondary canals. Basic information on each canal is given in Table 1.

Table 1. Basic Information on the sample secondary canals in the Pilot Project

Heran Distributary, including Khadwari Minor	
Design Discharge	58.0 cusecs (1.643 m^3/sec)
Number of Watercourses	30
Culturable Command Area	15,323 acres (6,204 ha)
Bareji Distributary	
Design Discharge	41.5 cusecs (1.176 m^3/sec)
Number of Watercourses	24
Culturable Command Area	13,563 acres (5,491 ha)
Dhoro Naro Minor	
Design Discharge	51.60 cusecs (1.462 m^3/sec)
Number of Watercourses	25
Culturable Command Area	13,382 acres (5,418 ha)

RESULTS AND DISCUSSION

The discussion of results is divided into three parts.

Part 1: External Equity or Water Allocation to Secondary Canals

Heran Distributary is the most favored of the three sample canals. Because it offtakes directly from the Nara Canal and it is able to receive reliable water supplies throughout the year at a level well in excess of the original design. Figure 2 shows actual and design discharges in both 1997 and 1999.

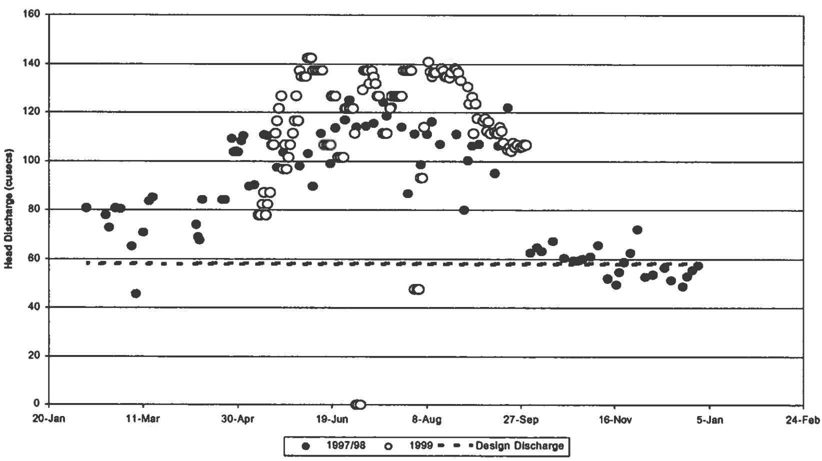

Figure 1. Heran Distributary Discharges

It is clear from Figure 1 that the Heran Distributary consistently receives far in excess of design discharge. There are three typical discharge levels: 100-140 cusecs in the peak of the summer (kharif) season equivalent to 0.57-0.80 l/sec/ha, 80 cusecs in the late winter season (0.45 l/sec/ha) when wheat is growing fast, and 60 cusecs (0.34 l/sec/ha) in early winter when cotton has been harvested and wheat is in the establishment phase. During the peak season the discharge is typically 200% of design, dropping to design discharges when demand is at its lowest level. One important element shown by these data is that there is no significant difference between the 1997/98 and 1999 data. In 1999 there is actually slightly more water delivered to the canal than in 1997.

Bareji Distributary shows a somewhat different pattern (Figure 2). In 1999, although overall discharges are higher than 1997, there is a rotation imposed upon the canal which closes it for approximately one week every four weeks. This means that the effective discharge is less than the daily discharge levels.

In 1997 kharif season the average daily discharge was 65.0 cusecs for the 13,592 acres (5502 ha) of irrigable land, or a daily discharge rate of 0.33 l/sec/ha. In 1999 the average discharge when the canal was open was 81.5 cusecs (0.41 l/sec/ha), a delivery rate 98% higher than design, but when the closure days are included the average delivery rate drops to 56.7 cusecs (0.29 l/sec/ha), only 37% above design. There is no data immediately available to determine if rotations occurred during the 1997 kharif season.

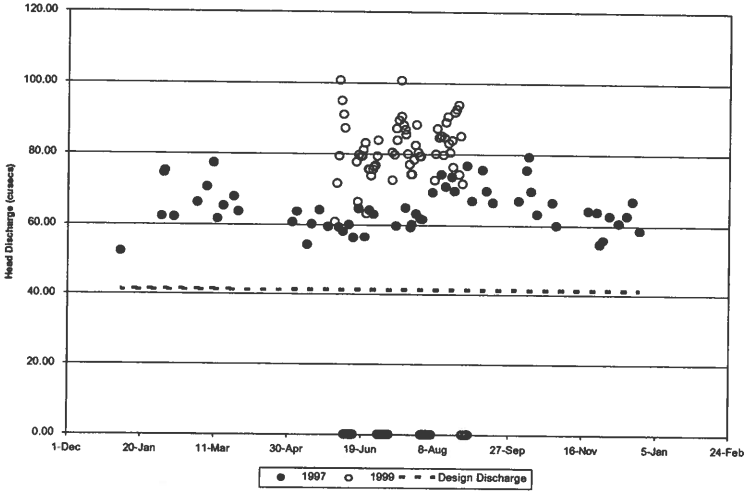

Figure 2. Head Discharges, Bareji Distributary

Dhoro Naro Minor shows a completely different pattern of water distribution and provides considerable more insight into management issues (Figure 3). In 1997 discharges were generally above design levels. The average discharge during kharif season was 59.7 cusecs for the 13,382 acres (5,418 ha) of irrigable land, equivalent to an average delivery rate of 0.31 l/sec/ha, and some 16% above design discharge. During this period the coefficient of variation of discharges was 16.5% which is considered acceptable under normal operating conditions.

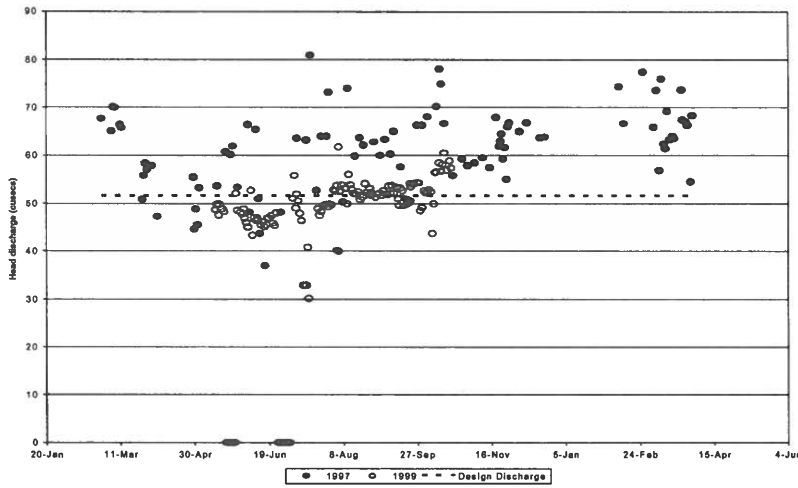

Figure 3. Head discharges, Dhoro Naro Minor

During the same period in 1999, however, discharges were significantly lower. On days when water was flowing, the average discharge was 50.4 cusecs, equivalent to an average delivery rate of 0.26 l/sec/ha and 98% of design discharge. If the rotation periods are included in these calculations, the average discharge drops to 44.87 cusecs, which is a delivery rate of only 0.23 l/sec/ha. This is only 87% of designed water delivery. At the same time, however, discharges were extremely stable: the coefficient of variation of discharge when water was flowing was only 9.6% which is considered very good.

Part 2: Issues of Internal Equity facing Farmer Organizations

Heran Distributary shows the importance of considering both absolute and relative equity (Example given in Figure 4). In terms of relative equity the data for 1997 show that the tail end-reach (the last five watercourses on the Distributary) get a lower proportion of available water than the other four upstream reaches. The head reach (Reach 1, or the first five watercourses) does not always get the highest share of water, this generally being experienced in the second reach (watercourses 6-9). However these differences hardly matter. With the exception of a few days during the entire season (7 occasions out of 48, and most of these were in April when wheat is being harvested so demand is less), the tail watercourses get more than their design share. It may be true that some farmers get twice as much as others, but this is comparatively equitable by typical standards in Pakistan.

An even more equitable pattern emerged in 1999 when discharges were more than twice design. While the tail end reach still received less water than the other reaches, and the head end reach received more than anyone else, all reaches received at least 50% more than design on every day of measurement. Under these conditions it is not worth the Farmers Organization spending much effort to reduce head-tail differences.

Their management concerns are likely to be rather different: protection of their land against waterlogging, and ensuring they do not get less water in the future. However, the latter issue is one that might emerge when the Area Water Boards become effective.

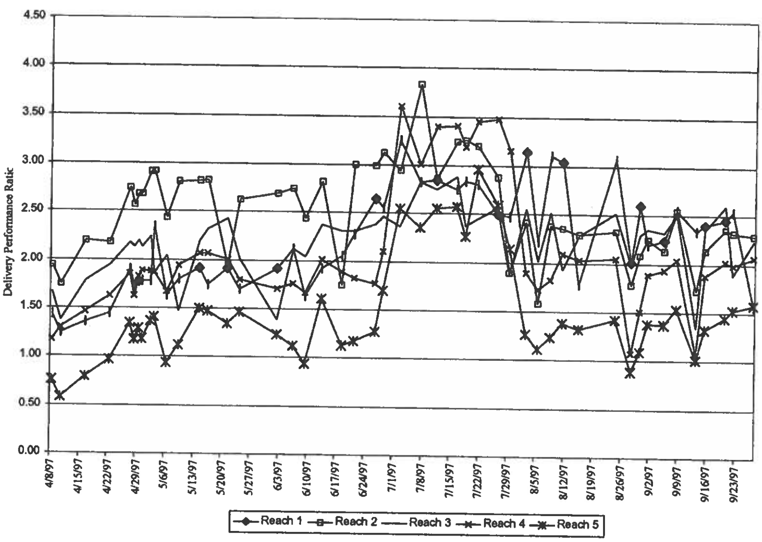

Figure 4. Water distribution equity, Heran Distributary, 1997

<u>Bareji Distributary</u> shows a similar pattern. Data for Kharif (Summer season)1997 show that there is no head-tail difference, and that all watercourses receive well over the design discharge. This is consistent with the data from the head gate which also show long periods when the total discharge available to the distributary are well in excess of design.

<u>Dhoro Naro Minor</u> shows a classic case where there is both absolute inequity and relative equity. Almost independent of the discharge at the head of the distributary, watercourses in the first reach (top 20% of all watercourses) receive more or less twice their design discharge. This is true whether the canal is

running at design or at 140% of design. In contrast, the tail end two reaches hardly receive any water when the canal is running at design discharge, and only reach design discharge at the tail when the canal is running substantially above design.

How Farmer Organizations can be Helped in Improving Internal Equity. In efforts to provide a simple but practical alternative, gauges were established in each of the three distributaries that can be used to give a quick indication of whether the head and middle reaches are receiving more than their fair share and whether water is in excess at the tail and the head gate opening needs to be reduced in order to prevent over-irrigation or waterlogging.

An example of correlation analysis between gauges along the distributary canal is developed and is presented in Table 3. In the case of Heran Distributary design discharge of 58.0 cusecs is achieved if the head gauge reads 1.85 feet. If the equity objective of farmers is to distribute this water equally between each reach then the middle gauge should read 1.70 feet (35.2 cusecs) and the tail gauge should read 1.64 feet (20.2 cusecs). If the middle gauge reading is less than 1.70 then the head reach is taking more than its fair share and some remedial action may be required to reduce discharges into one or more watercourses in the head reach.

Table 3: Management Table to Help in Determining Target Levels of Different Gauges: Heran Distributary

Head of Distributary			**Top of Tail Reach**			
Head Gauge (ft)	***Percent Design Discharge***	***Head Discharge (cusecs)***	***Target Discharge (cusecs)***	***Middle Gauge (ft)***	***Target Discharge (cusecs)***	***Tail Gauge (ft)***
1.42	70	40.60	24.64	1.21	14.14	1.26
1.57	80	46.40	28.16	1.38	16.16	1.39
1.71	90	52.20	31.68	1.54	18.18	1.52
1.85	100	58.00	35.20	1.70	20.20	1.64
1.99	110	63.80	38.72	1.86	22.22	1.76
2.12	120	69.60	42.24	2.02	24.24	1.88
2.25	130	75.40	45.76	2.18	26.26	1.99
2.37	140	81.20	49.28	2.34	28.28	2.10
2.50	150	87.00	52.80	2.50	30.30	2.21
2.62	160	92.80	56.32	2.66	32.32	2.32
2.74	170	98.60	59.84	2.82	34.34	2.42
2.86	180	104.40	63.36	2.97	36.36	2.53
2.97	190	110.20	66.88	3.13	38.38	2.63
3.09	200	116.00	70.40	3.28	40.40	2.73

Part 3: Overall Conclusions and Recommendations

Farmer Organizations have two specific and separate functions. The first function is to safeguard their overall right to a specific volume of water at the head of the canal, and the second function is to distribute that water among members in equitable manner as they see fit.

Water Allocations between Canals. Safeguarding a specific volume of water at the head of the canal assumes that there is some form of hydraulic contract between the Farmer Organization (FO) and the Area Water Board which has overall responsibility for management of water resources at the level of major canal commands. This contract can take one of several forms: the simplest form is design discharge, but it could be considerably more complex so as to accommodate changes in demand and supply during the year. Whatever the details of the agreement, the basic and non-negotiable condition is that the pattern of water deliveries is known in advance with respect to both volume and timing, and that both parties are able to mutually verify that these conditions are being met.

The present situation in the three distributaries shows that there is a long way to go before both sides can feel comfortable that they have an agreed set of hydraulic conditions. In Heran and Bareji Distributaries actual discharges far exceed design, but the Irrigation and Power Department (IPD) has indicated that as a special concession these above average discharges will be maintained. However, this indication cannot have legal status at present because officially IPD is only authorized to give design discharge. This dilemma for IPD needs to be resolved.

Similarly, Dhoro Naro Minor complains bitterly that it gets less water than before, and that it gets proportionally less than other neighboring canals. It is not easy to prove these complaints because most canal gauges are no longer accurate and information on discharges is not part of the public domain. Nevertheless, whatever the specific complaints at Dhoro Naro, Area Water Boards are going to have to get used to the reality of Farmer Organizations being able to measure discharges in their canals and to make this information public

Information about Deviations from Agreed Water Allocations. Reliability of irrigation water is not merely sticking to an agreed set of allocations. It also requires an effective communication framework that can substitute information for water when there is a need to make changes.

The classic case of this is information about rotations. If, for perfectly legitimate technical reasons, suppliers of water have to implement rotations then it is incumbent upon them to ensure that the starting and ending times of each rotation are known to everyone in advance, and that actual operations of gates and other structures are timed so that the pre-announced timetable is correctly followed.

If water users do not know when their water will be cut off, or when it will be restored, then this will lead to confusion and frustration and they will have some legitimate complaint to make concerning the management of the Area Water Board.

Mechanisms for Resolution of Disputes. Disputes that arise at present, and there are many, are solved in an ad-hoc manner, normally on the basis of a personal intervention rather than in any systematic manner that will form the basis for future resolutions. This type of approach to dispute resolution favors the supplier of water over the user of water.

If water users are more certain that the supplier of water is doing the best possible, and that there is some degree of mutual trust and tolerance established on both sides, then it is possible to create the conditions whereby improvements in water service delivery to FOs can be matched by improvements in the internal management of water by FOs internal to their distributary or minor.

Achieving Greater Internal Equity of Water Distribution. To date it is impossible to say with conviction that Farmer Organizations have made genuine and lasting improvements. There appear to be three primary reasons for this: differences in absolutely equity in the three pilot canals, weak internal mechanisms to identify what is considered fair, and the lack of an overall enabling framework.

Identifying what is seen as fair. The easy way out from the problem of identifying what is fair is to equate equity and equality. The old design concepts of the British followed this path, so that water was allocated almost entirely on the basis of land holding irrespective of physical, social or other factors.

Over time, for whatever reasons, be they head-tail differences, reflections of political or social differences, or reflections of who is a better farmer, some farmers get more water than others. The more favored ones are unlikely to willingly give up all of their extra benefits, but that does not mean they might not be willing to give up some part of their advantage.

If FOs are organized solely on the basis of equality, then they will probably fail in their efforts to achieve greater equity. Instead, they need to try to identify some rules of what might be considered fair, and the mechanisms by which these rules could be implemented by members of the FO.

IMPACTS FROM TRANSBOUNDARY WATER RIGHTS VIOLATIONS IN SOUTH ASIA

Miah M. Adel[1]

ABSTRACT

Indian operations of upstream water diversion constructions on transboundary rivers caused sedimentation in river beds and drops in river flows to no flows destroying the aquatic habitats for Gangetic fishes and dolphins, and shortage of irrigation water in Bangladesh. In the Ganges basin alone, floodplains and ponds face a water shortage by 50% causing destruction to the natural breeding grounds of 103 Gangetic fishes. Further consequences have been extinction and endangerment of aquatic species, malnutrition among people, loss of skilled professionals, a shift in agricultural practices, obstruction to pastimes, water sports, and religious observances, closure of irrigation and industries, over-dependence on groundwater, inland intrusion of saline water and damage to Sundarbans, climate change and outbreaks of environmental diseases, arsenic contamination of groundwater, the problem of rehabilitation of arsenic patients, and occurrences of devastating floods. Additionally, the upstream country has planned to divert water from the Brahmaputra, the Meghna, and the Tista, signaling the same series of effects for the remaining two-thirds of Bangladesh. To protect the riparian civilization and international water rights, the UN should play the key role to establish fair-sharing of water among the riparaian nations instead of leaving the issue with them.

INTRODUCTION

Bangladesh has 59 transboundary rivers with neighboring India. The principal ones are the Ganges, the Brahmaputra, the Meghna, and the Tista (Fig. 1). At least 30 rivers have upstream water diversion constructions out of which Farakka Barrage upon the Ganges is the most damaging one. It was built 18 km upstream from the Indo-Bangladesh common border to divert water flowing through the Bangladesh Ganges to the Bhagirathi in West Bengal to increase the navigability of the Calcutta Port located a 260 km downstream. The Bhagirathi lost navigability after the discharges of its tributaries from the west side were obstructed by major dams constructed under by Damodor Valley Corporation. Sourcewise, Bangladesh has 76.5% of its water from the transboundary sources, 22% from rainfalls, and 1.5% from groundwater (Hossain et al., 2003).

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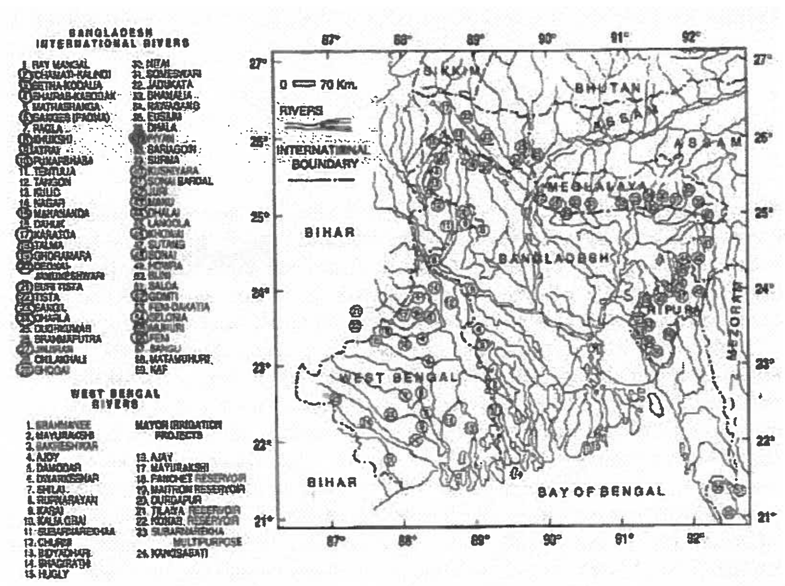

Figure 1. Transboundary rivers between India and Bangladesh

This article presents the downstream effects upon Bangladesh from upstream water withdrawals during the dry season and water release during the flood season by neighboring India, and suggests world nations to consider water diversion as important as an issue as the reduction of greenhouse gases in the atmosphere to save riparian civilization.

IMPACTS FROM HYDROLOGICAL CHANGES

Drop in Ganges Flow. The Ganges flows for pre- (prior to 1975) and post-Farakka periods at the Farakka point and the Hardinge Bridge point (about 174 km downstream from the Indo-Bangladesh border) have been compared in Fig. 2. It shows severe dry season drops in flows at the Farakka point in 1980 compared to that in 1900 and 1850. The drops at the Hardinge Bridge point are shown for 1963 and 1993. Water withdrawals in all seasons are noticeable from the comparison of curves for 1963 and 1993. The low flows have created sedimentation on river beds, particularly, at the points of origin of the distributaries where the current speed drops due to change of direction of the current into the distributaries.

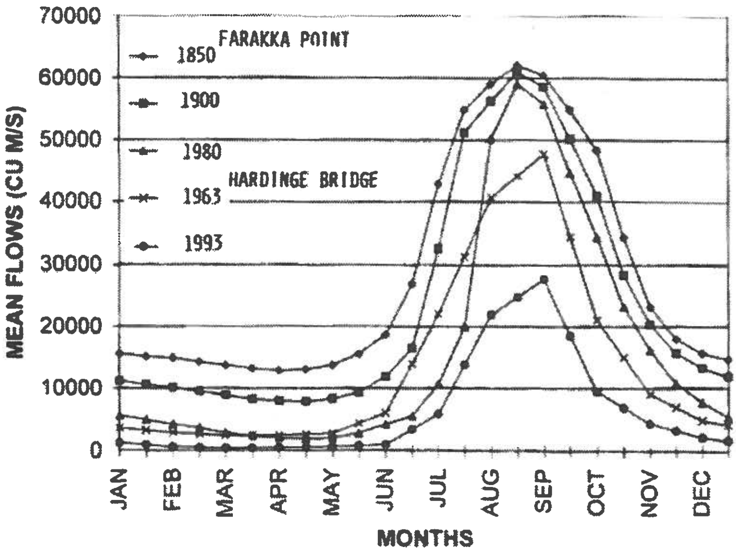

Figure 2. Decreasing flows at both the Farakka and Hardinge Bridge points

Conditions of Distributaries. The Baral (about 80 km long) is the first distributary of the Ganges in Bangladesh. The perennial water source is mostly dry in its first 30 km –course and sites beyond this due to the development of a huge shoal of about 1 x 0.50 sq km at the mouth. The Musa Khan River originates from the Baral at about 20 km downstream. All the aquatics and amphibians that lived year-round in stretch of 20-km watercourse in the Musa Khan are gone forever. The frolicsome scene of the Gangetic dolphins in this river is a legend now. More than 900 sq km of the basin area has not received the Ganges water since 1975.

The Gorai (50 km downstream) is the principal distributary of the Ganges. The water course is about 225 km long. The basin area is at least 10,000 sq km. The decreasing trend in discharge is presented in Fig. 3. Also, huge shoals have appeared in the Gohrai bed.

In a ten-year (1973-83) survey of the Ganges and the distributaries, the total number of shoals increased by more than 6 times, the areas of shoals increased by more than 10 times, and areas of the distributaries decreased by 2.5 times (Elahi and Saleheen, 1992). Shahjahan estimated that, as of 1993, 2,500-miles inland navigable routes were shrunk to 600 miles due to the water withdrawal (Shahjahan, 1993).

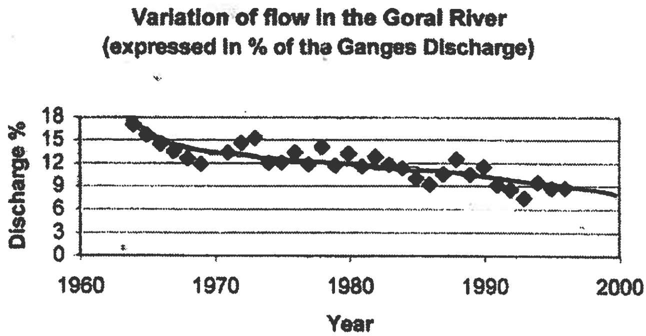

Figure 3. Decreasing flows in the Gohrai

Floodplains. Floodplains holding water for 12 months within depths of 1.1 to 2.2 m, 10 to 11 months within depths of 0.70 to 1.120 m, and 8 months within depths of 0.25 to 0.60 m, can now hold water for 6 months, 4 months, and 1 to 3 months, respectively. An overall water drop is about 50%. Surveys of ponds also showed a similar decrease.

Depletion of Fish Breeding Grounds. The loss of water by floodplains has depleted the natural fish breeding grounds in flood plains and canals. Fish had been the cheapest source of animal protein (6.25%), one of the indispensables of life, and calcium (25%). In 1981-82, 76 and 97% of the project area population had calcium and protein deficiencies. Now, in the event of almost doubling the population, this cheap nutrient source is scarce. Further, frogs, snails, turtles, and disliked species of fishes were rendered extinct because of the loss of their habitat before an inventory could be made.

Loss in Industrial Sector. Shoals in the Ganges and its weak flow fails to provide adequate water for production factories like paper mills, jute mills, nerwspint mill, and power station, and irrigation projects, and river port operation. From December 1975 to June 1976, Bangladesh faced a loss of about $783 million in the industry sector (Crow et al., 1995).

Inadequate Recharging of Groundwater. Due to the reduction of the available size of natural recharging grounds (floodplains, ponds, canals, and ditches) and quantity of recharging water, and overdependence on groundwater in irrigation, bathing, washing, etc., groundwater table is sinking. In pre-Farakka days, depth of handtubewells was 8 m, at most. In post-Farakka days, Tara pumps are replacing handtubewells. These pumps are set to a depth of more than 15 m.

IMPACTS FROM CLIMATIC CHANGES

Climatic Changes and the Consequences. From the analysis of pre- and post-Farakka climate data, it was found that rainfalls decreased by 30%. Also, the heating and cooling degree days increased by 1.33 and 1.44 times, respectively, in the post-Farakka era (Fig. 4). Further, weather-related discomforts of the pre-Farakka days are now occurring at relatively low temperature and humidity in post-Farakka days. Temperature variations are causing hypertension, stroke, and several other diseases (Adel, 2002).

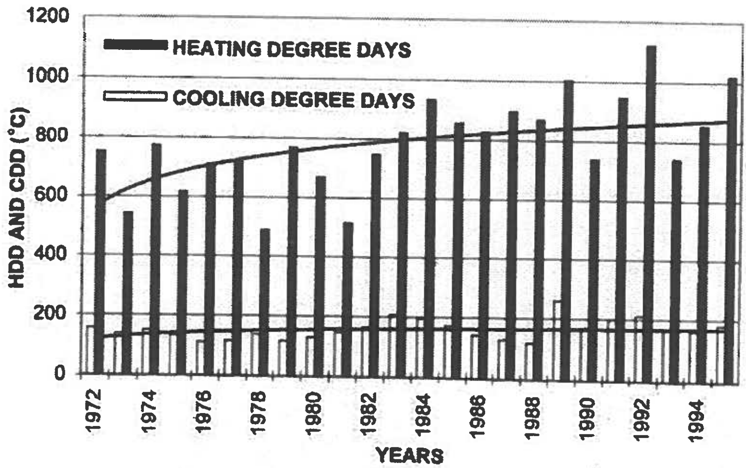

Figure 4. Heating and cooling degree days are on the rise

Salinity Intrusion. Low river flows has favored inland salinity intrusion affecting the timber production from trees like Sundari, Gewa, Keora, etc. in the Sundarbans the world's largest mangrove forest and destroying more than 60% of the marketable timber.

IMPACTS FROM SOCIETAL CHANGES

Shifts in Agriculture and Professions. Due to the shortage of water, farmers cannot produce jute that needs retting water. The cash crop jute is replaced by rice and sugar cane cultivation. Jute would give them cash in hand during the annual bad economic. Also, many of the rural professionals have forgot their skills for not having an opportunity to use them. Besides, cottage industries in the Ganges delta have been destroyed. In golden days of fishermen during the pre-diversion era, an average size fishermen's village having about 150 fishermen, could make about 350 fishing nets of 20 varieties for catching 15 to 20 types of fishes.

Obstruction to Religious Observances, Water Sports, and Pastimes. The Hindus, the main minority group in Bangladesh cannot perform the post-funeral pyre rituals. With the depletion of surface water resources no opportunities for the angling pastimes exist. The post-Farakka generation in many areas of the Gangetic Bangladesh cannot learn swimming and other water sports because of the lack of the facilities.

IMPACTS FROM GEOCHEMICAL CHANGES

Groundwater Contamination. Arsenic contaminated groundwater has plagued the Gangetic Bengal basin. Fig. 5 illustrates the level of contamination. It is believed that the sinking water table has increased the aeration zone exposing buried arsenopyrites to atmospheric oxygen to form water-soluble compounds. Later, the water-soluble arsenic compounds mixes with groundwater via infiltration. It is a huge social problem for the government to treat and rehabilitate the arsenic patients. It has rendered the society unstable because of marriage break-up if a spouse is affected by arsenic.

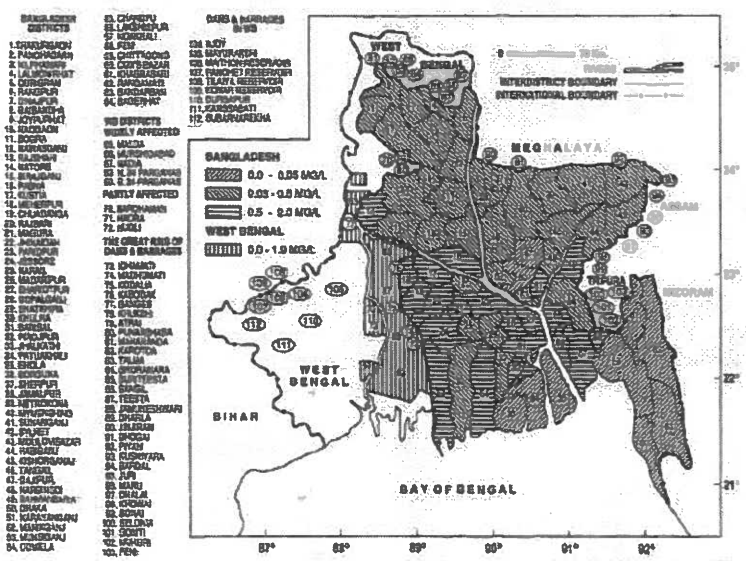

Figure 5. Arsenic affected areas in Bangladesh and West Bengal in India

Other Water Diversion Construction. The Tista River originates in the hilly region of northern Sikkim and flows for 112 km before meeting with the Brahmaputra at Chilmaree. The average width of the river is 160 m. India's withdrawals of 42.5

m^3/s of water in the dry season affects agriculture and navigation in the Tista basin. Also, the water diversion from the Mahananda river during the dry season affects agriculture, industry, employment, and natural balance in the Mahanda basin.

Increase of Flood Frequency. The upstream country uses dams as flood outlets when she cannot withhold the rising flood water. Sometimes, the Bangladesh border forces have to guard against the upstream country's border security forces' action of water release through Bangladesh (Adel, 2001). Floods take away lives and properties. Tens of kilometers of arable land are eroded away that are deposited as sediment downstream to cause inland navigation problems cutting off between the northern and the central part of the country. Fig. 6 shows no reduction of flood devastations in the post-dam era. The mid-July flood alone cost about US $7 billion in 2004 surpassing all previous records while August flood is yet to come.

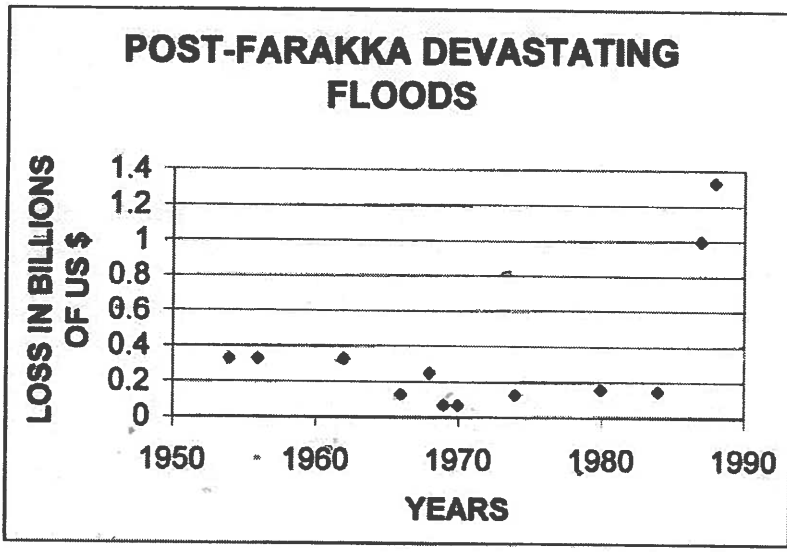

Figure 6. Devastating floods occur in post-Farakka days

Brahmaputra. Under a grand river networking plan, India will take the water from the Brahmaputra to the Cauvery of south India through about 1,500 km canal. The distributaries of the Brahmaputra in Bangladesh are the Old Brahmaputra (branches off at about 55 km downstream, 6,400 sq km basin area) and the Dhaleshwar (branches off at about 150 km downstream and about 3,200 sq. km basin area). Fig. 7a, 7b show the already dwindling flows in the old Brahmaputra and the Dhaleshwari (courtesy of Hossain et al., 2003)

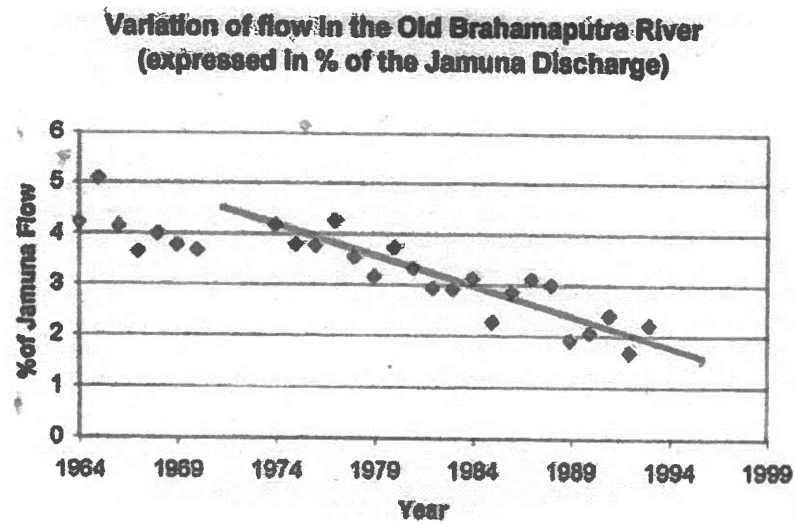

Figure 7a. The already dwindling flow of the Old Brahmaputra

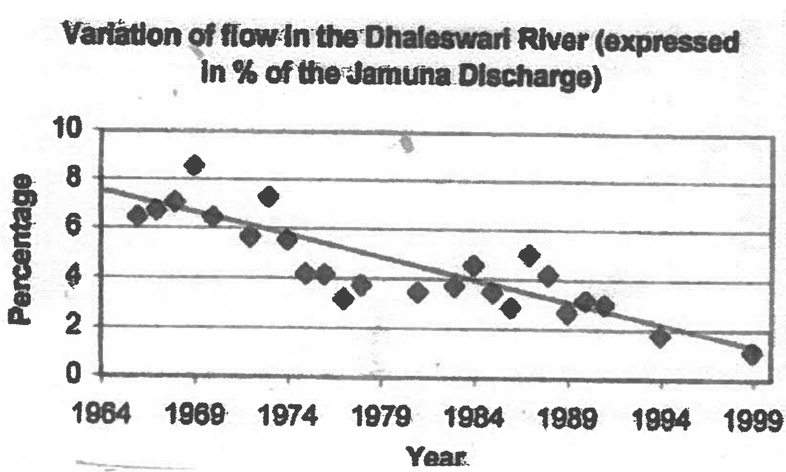

Figure 7b. Decreasing flow in the Dhaleswari river

Water Diversion From the Meghna. The Meghna river washes the north-east past of Bangladesh. Several transboundary rivers form its head stream. The Barak Barrage (315 - high and 161-m long) built near 25 degree parallel at Teepaimukh located between Assam and Monipur provinces, will store about 16,000 cubic meter of water (Satter, 1998). Water diversion by this barrage will cause ecocide in the Meghna basin.

Total Impact. The total impact for a developing country is TS = 630a + 410b + cd (Foster, 1976; 1980) where TS = total stress; a = number of deaths which are related to floods, environmental diseases like asthma, hypertension, stroke, heatstroke, cold, fatal accidents, arsenic toxicity = 40,000; b = number of injuries which include all the sources for a, and additionally, from malnutrition following loss of fishes = 20,000,000; c = stress resulting from damage to the infrastructure which includes whole infrastructure of water supply in natural sources = 65 < c < 145; and d = population affected by the event = 40,000,000. Thus the estimated disaster figure lies in the astronomical range!

Solution. World nations should get together to sign protocols like the Kyoto and Rio to maintain availability of quality water for all living beings. Water sharing treaties should be formulated, implemented, and supervised under UN observations. Violators of water rights should be punished by UN sanctions. Bangladesh needs international assistance to excavate her silted river and canal beds and build embankments for drainage and storage of excess water for wet and dry seasons and to reestablish the lost wetland ecosystem.

CONCLUSION

Water diversion constructions are like lock and keys in the hand of upstream country to control river flows. She uses the mechanism to divert the lean season flow depriving the downstream country and to release the flood season excess water to submerge the downstream country. Upstream dams and barrages have raised downstream river beds affecting agriculture, hydrometeorology, industry, navigation, and people's livelihood. Floodplains, the natural wells for recharging groundwater and the natural breeding grounds of fishes, fail to serve either purpose. This results in extinction of sweet surface water and sinking of groundwater sources. Fishes are becoming extinct. Oxygen-sensitive toxic minerals like arsenic buried in the alluvial soil are forming water-soluble compounds to contaminate groundwater. Further potential problems are beset with the upstream country's grand river linking plan to divert water from the Brahmaputra and the Meghna rivers. Feedback effects from each of the affected sectors further aggravate the situation. World nations should get together to establish international water rights laws to protect south Asian sweet water resources. Interests of all riparian nations should be considered for formulation, implementation, and supervision of all water sharing treaties under the auspices of UN. Bangladesh needs international assistance to make her rivers navigable and to construct embankments on them for flood protection.

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IMPACTS OF WATER CONSERVATION AND ENDANGERED SPECIES ACT ON LARGE WATER PROJECT PLANNING, UTAH LAKE DRAINAGE BASIN WATER DELIVERY SYSTEM, BONNEVILLE UNIT OF THE CENTRAL UTAH PROJECT

Mark A. Breitenbach, P.E.[1]

ABSTRACT

Planning, design and construction of the Central Utah Project has spanned five decades and is currently anticipated to be completed approximately 60 years after its initial authorization by the U.S. Congress. in 1956. During the latter part of this time, the State of Utah, through a high influx of population, has been transformed from a predominantly static agricultural and mining economy to a rapidly expanding recreational and high tech urban economy. Conversion of agricultural lands to residential housing and the finite available water supply has necessitated changes in the Central Utah Project plan of 1964 from a traditional agricultural water delivery project to a municipal and industrial water delivery project in 2004. Water planners must increasingly turn to water conservation, water re-use, conjunctive use of water supplies and de-salting of brackish water to meet future population growth, while meeting the challenge of preserving and enhancing local streams and the environment.

INTRODUCTION

The Utah Lake Drainage Basin Water Delivery System (ULS) is a component of the Bonneville Unit of the Central Utah Project (CUP). The CUP was authorized in 1956 (Public Law 84-485) as a participating project of the Colorado River Storage Project (CRSP) to develop and distribute a portion of Utah's share of Colorado River water for use in the Uinta sub-basin of the Colorado River Basin and, via a trans-basin tunnel, to the Bonneville sub-basin of the Great Basin of Utah.

The Bonneville Unit was originally planned to include 1) a Municipal and Industrial (M&I) System that would store and deliver water for municipal and industrial purposes to the most populous areas of Utah from Provo City to Salt Lake City in northern Utah and 2) an Irrigation and Drainage (I&D) System that would deliver agricultural water to the more rural areas of Utah in the central and southern portions of the State. Other systems of the Bonneville Unit were primarily planned with the purpose to intercept, collect and store Colorado River

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drainage basin runoff and convey the Colorado River water supply to the Great Basin of Utah for use in the M&I System and I&D System areas. These collection systems would also provide a smaller quantity of water for use locally within the Uinta Basin.

The M&I System and the collection system storage reservoirs, tunnels and pipelines were completed first essentially as originally planned. The I&D System has undergone significant modifications over the years, including 1) conversion to a wholly municipal and industrial system with streamflow enhancements, 2) changes in project service area and 3) a change in system name from the I&D System to the Utah Lake System and 4) changes in project planning and construction from Federal administration to State administration by the Central Utah Water Conservancy District (District) with Federal oversight by the U.S. Department of Interior (Department).

Rapid urban growth, conversion of farmland to residential housing and water conservation features have significantly affected the change in project scope from what was anticipated at the time of the 1956 project authorization.

BACKGROUND OF THE CENTRAL UTAH PROJECT

In 1922 the Colorado River Compact divided the water supply yield of the Colorado River among seven basin states comprised of portions of Wyoming, Colorado, Utah, Nevada, New Mexico, Arizona and California. The State of Utah was allocated a percentage of the water supply of the Colorado River. The yield of the State's portion is estimated to be 1.7 million acre-feet annually (21 billion cubic meters).

The Central Utah Project was authorized in 1956 as a Federal water delivery project to assist the State of Utah in developing a portion of its share of the water supply of the Colorado River Basin. Figure 1 shows that the CUP was originally organized with five planning units, each with its own independent water supply collection and distribution plan within the unit boundaries. Four of the five CUP units were planned to intercept runoff from the Duchesne and Green River watersheds (tributary streams to the Colorado River) and deliver the intercepted water for local agriculture and limited municipal use.

The majority of the State of Utah's population and agricultural industry, however, is not located within the Colorado River Drainage Basin. The fifth and largest unit, the Bonneville Unit, was planned to intercept runoff of the Duchesne River watershed and deliver municipal and agricultural water to the most populous areas of Utah, located in the Great Basin, by means of a transbasin tunnel. The Great Basin is a series of sub-basins that are "closed", meaning they are basins with no drainage outlet to an ocean. Runoff from springtime snowmelt in the mountains collects in shallow saline lakes and salt flats and evaporates. Two of the largest lakes within the Great Basin are the Great Salt Lake and Utah Lake.

Approximately 320,000 acre-feet (400 million cubic meters) of water evaporates annually from the 80,000 acre (32,400 hectare) surface area of Utah Lake, a shallow semi-freshwater lake with a storage volume of 870,000 acre-feet (1.1 billion cubic meters) at the designated "full" level. Salt concentration ranges from a low of 450 milligrams per liter Total Dissolved Solids (TDS) during flood years to in excess of 1500 mg/l TDS during extended droughts, with an average long-term salinity of approximately 850 mg/l TDS. Annual evaporation from Utah Lake is approximately 50 percent of the total inflow, resulting in more than a doubling of salinity at the lake outflow point into the Jordan River that flows to the Great Salt Lake.

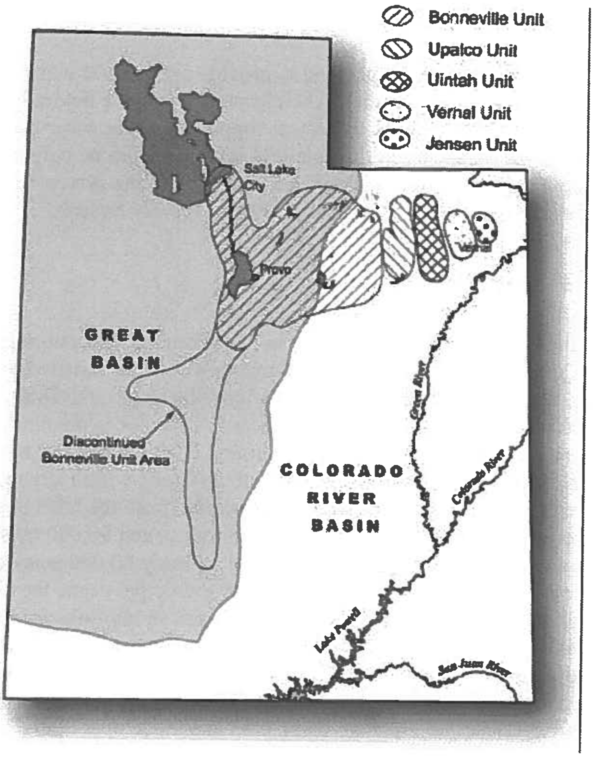

Figure 1. Location of CUP Planning Units

The Great Salt Lake has a surface area of 1.3 million acres (526,000 hectare) with approximately 2.9 million acre-feet (3.6 billion cubic meters) of annual net evaporation. The level of the Great Salt Lake rises and recedes depending on the hydrologic conditions of the local runoff. The typical salinity of the Great Salt Lake is about 230,000 mg/l TDS, which is about 7 times saltier than the oceans.

The Irrigation and Drainage System

Early CUP planning for the I&D System investigated reducing evaporation from Utah Lake by diking and draining shallow bays to create a new local water supply and improving lake water quality through reducing inflows from mineral springs and saline seeps. Public opposition to changing the configuration of the lake and reclaiming areas for agricultural purposes resulted in abandonment of the plan to reduce Utah Lake surface area a water source. The modified plan relied on importing Colorado River water and acquisition of existing water rights within Utah Lake.

The I&D System was originally planned to provide agricultural water to parts of eight counties in central and southern Utah located within the Sevier River and Utah Lake drainage basins. Lack of project support by some water users in the southern part of the State caused the potential service area to be reduced to only the Utah Lake Drainage Basin as shown on Figure 1 and the system to be renamed as the Utah Lake Drainage Basin Water Delivery System.

The Utah Lake System

A notice in the Federal Register was filed in 1998 formally discontinuing the I&D System. In 2000, a notice was filed that planning was being initiated on the Utah Lake System that would deliver water only within the Utah Lake Drainage Basin. The Utah Lake System plan is shown on Figure 2. It includes pipelines to convey municipal water to Salt Lake County and southern Utah County and to convey supplemental water to the Provo River and Hobble Creek within Utah County for streamflow enhancement. Requests for water service from the ULS totaled 200,000 acre-feet, comprised of 120,000 by M&I users and 80,000 by agricultural users. With a remaining potential Federal supply of only 60,000 acre-feet (74 million cubic meters) and with priority shifted to municipal users, the ULS was configured as a municipal water delivery system with streamflow enhancements. Temporary agricultural water will be available on a year to year basis for a limited area with existing diversion facilities from the Spanish Fork River. This temporary agricultural supply will diminish as lands are urbanized and ULS facilities serving municipal users are completed and made operational.

The Water and Conservation Program Under CUPCA

Another key water supply improvement component of CUPCA is the Water Conservation Credit Program (WCCP). This program authorized a comprehensive program to improve water management within the CUP service area, including the establishment and achievement of water conservation goals by year 2010. To achieve this purpose the District developed a Water Management Improvement Plan to assist local agencies in funding measures. The District's water conservation goal was originally established at 39,294 acre-feet (48.5 million cubic meters) of savings per year. However, strong local support has indicated that a greater potential exists, and the District has increased its goal to 62,100 acre-feet (76.6 million cubic meters) of water savings per year after 2016. The District has funded approximately 30 WCCP projects. The WCCP provides a means to reduce water shortages in areas of the District beyond just those areas where water delivery features are constructed. Areas originally planned to receive supplemental agricultural water under the original I&D System plan therefore still have a means to reduce water shortages and benefit from the Central Utah Project.

The 1992 Central Utah Project Completion Act (CUPCA) included authorization of $50 million for water conservation projects and $10 million for surface and groundwater conjunctive use. An amendment to CUPCA occurred in December, 2002 authorizing delivery of municipal water was a project purpose and expanding the water conservation and conjunctive use programs. The amendment added water recycling and reverse osmosis of brackish water as authorized features and increased Federal funding authorization for all four purposes by $300 million.

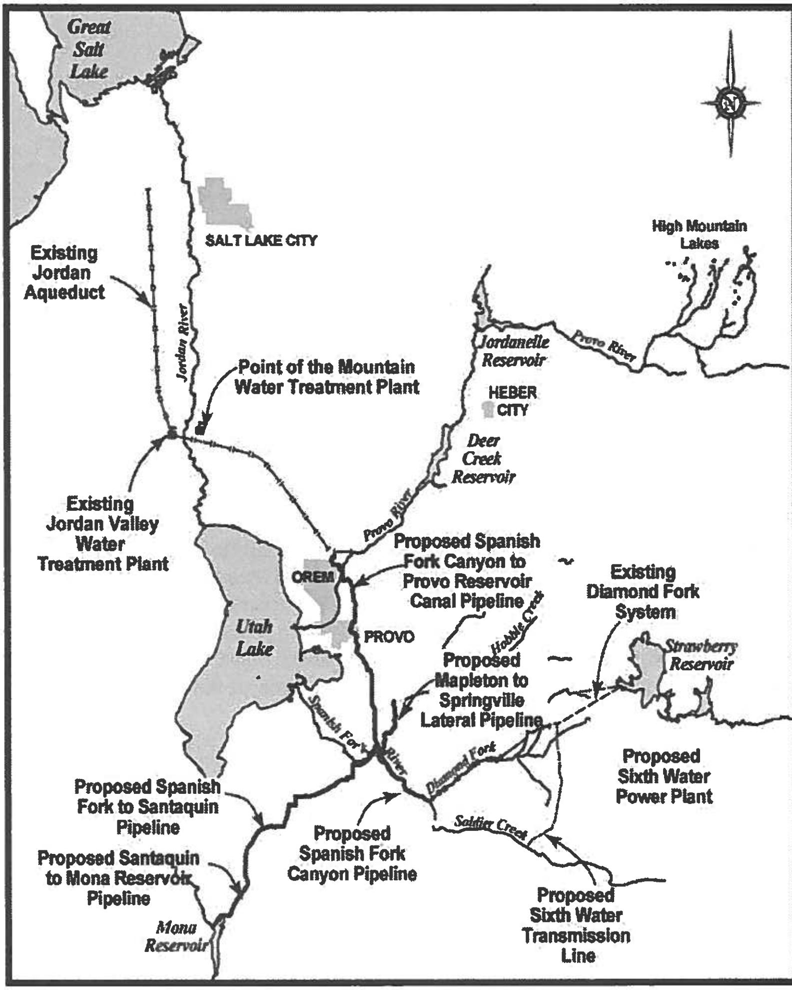

Figure 2. Utah Lake System Plan

AFFECTS OF WATER CONSERVATION ON PROJECT PLANNING

Urbanization of agricultural lands and water conservation by both agricultural and municipal water users had a profound affect on the configuration of the final project plan.

Agricultural Affects of Water Conservation

Water supply evaluations have traditionally been approached by first determining the need for water and then comparing the need with the available usable water supplies on a monthly basis; the difference being the water supply shortage. Early CUP planning for the I&D System component of the project focused on determining and certifying arable lands within the CUP service area through field investigation and classification of the soils. Arable lands are lands that could be economically suitable for raising crops if a water supply was available to them. After determining the arable lands, those arable lands that could be provided a water supply were defined as "irrigable" lands and included in the project planning.

In the 1950's and 1960's farms in Utah were mostly comprised of alfalfa and grass hay and were predominantly irrigated by the flood irrigation method. Unlined earthen ditches diverted water from rivers, creeks and local springs and conveyed the water to hayfields where the water sheet flowed across the ground. Water losses in irrigation conveyance ditches were typically 25 percent and often ranged from 10 to 35 percent of the amount diverted at the head of the canal. The on-farm irrigation efficiency (crop consumptive use divided by applied water) of flood irrigation is typically about 50 percent, meaning only 50 percent of the water reaching the fields from the conveyance ditches was effective in meeting crop water needs and the remainder percolated into the ground below the root zone raising groundwater levels, creating or enlarging wetlands and increasing seepage to the local streams. Overall irrigation efficiency was therefore 0.75 x 0.50 = 37.5 percent. Hayland with a unit consumptive use of 2 feet (0.61 meter) depth of water per area irrigated required 2/0.375 = 5.3 feet (1.62 meters) of water for maximum crop yield. Because a majority of the water supply source was unstorable springtime snowmelt runoff, available water typically exceeded crop needs in the spring months and resulted in shortages in the later summer months of July and August.

Some benefit was obtained by diverting as much runoff as possible in the spring, thereby temporarily storing (banking) the water in the shallow groundwater basin so that sub irrigation by water within the root zone extended the crop yield during the later summer months. The Morse Decree issued in 1901 defining water rights on the Provo River recognized the benefit of springtime over-diversions by upstream water right holders. Unconsumed water diverted from the Provo River in May and June within the Heber Valley infiltrated the ground and seeped to the Provo River, increasing river flows in the low flow months of July and August, a lag time of two months. The Morse Decree provided that junior water right holders could divert the flows of the Provo River ahead of the more senior downstream water right holders because senior water right holders benefited from higher river flows in the late summer low flow months.

Beginning in the 1980's and continuing to the present, water conservation improvements in irrigation and municipal use greatly changed the timing and need for water in Utah. Many flood irrigated areas converted to the wheel roll sprinkler irrigation method, often with the financial and technical assistance of State and Federal programs. These conversions increased the efficiency of applied on-farm water from less than 50 percent efficiency to approximately 65 percent efficiency. Canals were replaced by pressure pipelines resulting in further seepage and loss savings of an additional 25 percent or more. Overall irrigation efficiency therefore increased to about 65 percent, resulting in a unit diversion requirement depth reduction from 5.3 feet (1.62 meters) to approximately 3.0 feet (0.91 meter) per area irrigated, a savings of 43 percent.

Those irrigators who took advantage of programs to convert to sprinkler irrigation did not eliminate irrigation shortages, however the frequency of irrigation shortages was reduced in some areas from 8 out of 10 years to 2 out of 10 years by changing irrigation application and conveyance methods. In some cases funds to increase irrigation efficiency provided a greater benefit and more crop yield increase than if supplemental Federal irrigation water alone had been made available.

The original Bonneville Unit Area shown in Figure 1 included all or portions of ten counties. The southernmost counties were rural in nature. Two counties de-annexed from the District rather than participate in the Federal project and chose to pursue local water planning. Plans to construct a pipeline to deliver additional Federal water to three additional counties were eliminated from the Bonneville Unit plan and replaced by local water conservation improvement projects with 65 percent Federal funding assistance.

Municipal Affects of Water Conservation

From the 1950's to the 1980's, municipal and industrial unit water use remained relatively unchanged within Utah as a result of readily available water supplies, slower growth and development of lands with existing water supplies that could be converted to municipal use. Rapid urban growth has resulted in development of large areas of land previously without water rights. Urbanization of dry lands has resulted in competing demands for the available water supplies. The State of Utah has established a Water Conservation Goal of 12.5 percent reduction in unit water use by the year 2020 and 25 percent reduction in unit water use by the year 2050 as compared to 1995 unit water use rates. The State of Utah determined that the statewide overall unit municipal and industrial water use was 341 gallons per capita day (gpcd) in 1995 (1,291 liters per capita day). A goal of 25 percent reduction in unit water use would result in a unit use of 256 gpcd (969 lpcd) or less by the year 2050. Unit water use is typically 70-80 gpcd (265-303 lpcd) for indoor residential use, with the remaining amount used for outdoor landscaping and commercial and industrial uses. Therefore the majority of the water use reduction would occur from outdoor watering conservation.

The Governors Office of Planning and Budget projects that a statewide 25 percent reduction in unit use would reduce residential and municipal water use by approximately 400,000 acre-feet (493 million cubic liters) in the year 2050. The same 25 percent reduction goal applied to the10-county service area of the CUWCD, which has a lower unit water user rate than the remainder of the State, would result in a unit water use reduction of about 65 gpcd (246 lpcd), or approximately 225,000 acre-feet (278 million cubic meters) per year by the year 2050 when the population within the District's service area is estimated to reach 3.1 million people.

Under the Utah Lake System planning, petitioners for the remaining Bonneville Unit Water would be required to commit to reducing unit water use in accordance with the State goal. Unit water use by ULS petitioners is expected to range between 188 and 220 gpcd (712-833 lpcd) or less by the year 2050 to meet the 25 percent reduction goal. In some areas, conservation plans have been accelerated to achieve this reduction much sooner.

CHANGES IN RETURN FLOWS

Return flow is defined as water diverted from a reservoir or stream that is not consumptively used by an agricultural, municipal or industrial water user, or otherwise removed from the hydrologic basin. Consumptive use could occur through evapotranspiration from crop areas or by means of municipal and industrial consumption or evaporation from a water body surface. Water that is not consumptively used infiltrates the ground and seeps into the groundwater basin or directly returns to a stream or water body, making the water available for re-use by a downstream water right holder. In central Utah, most groundwater areas are fed by spring runoff and snowmelt infiltration. The groundwater drains into streams and lakes, often with less than a year of retention time within the groundwater basin. Increased groundwater withdrawals are therefore managed as reductions in downstream surface water supplies, requiring purchase and retirement of a downstream surface water right of equal quantity in order to withdraw the groundwater.

Water conservation, shift in use of water from agricultural to M&I use, and increases in irrigation efficiency result in decreased diversions from rivers and greater consumptive use of the smaller amount of water that is diverted. Consequently these factors reduce the amount of project water return flows available for re-use and reduce the overall amount of Federal water available for contracting.

The 1964 plan for the Bonneville Unit showed approximately 126,000 acre-feet (155 million cubic meters) of unconsumed delivered project water (return flow) with approximately 68,000 acre-feet (84 million cubic liters) of this return flow amount available for project re-use. Return flow that is determined by the State to belong to a downstream senior water right holder is not available for project re-use. Return flows in the 2004 project plan are approximately 75,000 acre-feet (93 million cubic meters) of unconsumed project water of which only about 17,000 acre-feet (21 million cubic meters) would be contracted and directly re-used as part of the Federal water supply. An additional 21,000 acre-feet (26 million cubic meters) of the unconsumed project water reaching wastewater treatment plants in Salt Lake County is planned to be re-used by water users as a non-Federal water supply resulting in a total allowable re-use amount of 38,000 acre-feet (47 million cubic meters). Increased environmental uses and water conservation have therefore reduced return flows by more than 40 percent.

AFFECTS OF ENDANGERED SPECIES ACT AND ENVIRONMENTAL STREAMFLOW ENHANCEMENTS

Water released for aquatic benefits have increased substantially over the years. The streams with minimum instream flows or dedicated quantities of supplemental water are shown in Figure 3. The 1964 Bonneville Unit plan included 5,000 acre-feet (6 million cubic meters) of water to be released to supplement low stream flows within the Strawberry River below the enlarged Strawberry Reservoir in the Unita Basin. The 1988 plan increased this amount to 6,500 acre-feet (8 million cubic meters). The 1998 plan expanded the streams to be supplemented within the Uinta Basin to four and increased the amount of water dedicated for instream flow to 44,400 acre-feet (55 million cubic meters). The increase in water available for stream flows in the Uinta Basin was largely made available by reducing the amount of transbasin diversion from Strawberry Reservoir to the Great Basin by 40,600 acre-feet (50 million cubic meters).

As a result of the 1992 CUP Completion Act, irrigation transbasin diversions from the Upper Strawberry River to the Provo River drainage in the amount of 2,900 acre-feet (3.6 million cubic meters) were terminated, further increasing the flow available for streams. Elimination of irrigation diversions above Strawberry Reservoir restored the natural flow in the Strawberry River upstream of its inflow point to Strawberry Reservoir, as well as several of the river's smaller tributary

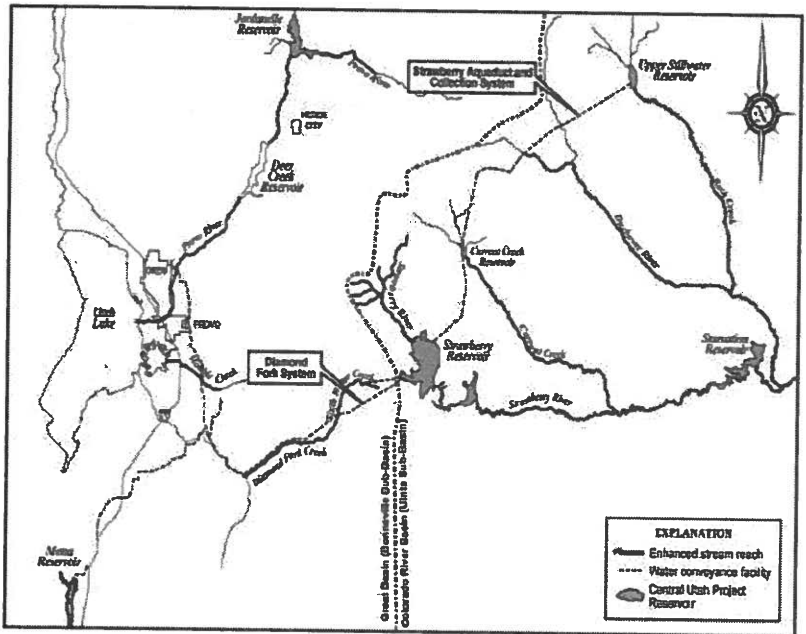

Figure 3. Bonneville Unit Stream Enhancements

streams, each of which had a diversion structure and interconnecting conveyance canal to the transbasin divide. The 1992 CUP Completion Act established minimum instream flows on the Provo River using project storage in Jordanelle Reservoir and storage in high country lakes. The Act established minimum instream flows in Sixth Water and Diamond Fork Creeks where transbasin Bonneville Unit conveyance facilities were sized to remove transbasin water from the streams in excess of desired fishery flows, except under certain operation conditions. Mandatory year-round minimum instream flow requirements range up to as high as 125 cubic feet per second (3,540 liters/second) in the reach of the Provo River immediately below Jordanelle Reservoir. These instream flow additions did not require a new specific water supply allocation because the water released for stream flows could be delivered to downstream water users or recaptured and regulated in downstream non project reservoirs for subsequent exchange. Consultations with the Utah Division of Water Rights were required to assure exchanges did not interfere with existing water rights. A new pump back system was necessary to redivert instreamflow water on the Provo River at the end of an instream flow reach during periods when the instream flow requirement ia greater than downstream water user demands in order to recapture and pump the water to an upstream aqueduct.

The 2004 Bonneville Unit plan added features to provide the ability to manage and supplement the flow of three rivers for an endangered fish. In 1986 the June sucker, an endemic fish native only to Utah Lake, was listed as an endangered fish under the 1973 Endangered Species Act. Once abundant in Utah Lake, the population of June sucker in the lake plummeted from an estimate in the millions in the 1800's to only about 300 fish in 1998 as a result of land development affecting habitat and the introduction of non native fish. In the 1990's, successful spawning of June sucker was limited to only one tributary of Utah Lake, the Provo River.

The June Sucker Recovery Implementation Program (JSRIP) was established with the dual goals of successful recovery of the fish while maintaining supplies to water users. Environmental commitments were included in the planning of the Bonneville Unit to assist the JSRIP in the recovery of this fish species. The Bonneville Unit plan was developed to include three elements that directly assist the JSRIP in its June sucker recovery efforts. First, water conservation funding to reduce or eliminate canal seepage and water distribution system losses will result in 12,165 acre-feet (15 million cubic meters) of conserved water on the lower Provo River that will be regulated by reservoirs and managed to improve flows for June sucker spawning. Second, ULS pipelines will be sized to convey up to 75 cfs (2,124 liters/second) of transbasin imported water from Strawberry Reservoir to the Provo River (an average of 16,000 acre-feet (20 million cubic liters) per year with no supplemental water in some years) to increase minimum river flows. Third, conveyance facilities will provide an average of approximately 12,000 acre-feet (15 million cubic meters) of water to Hobble Creek in an effort to establish a second spawning stream for the June sucker. The supplemental water supply to Hobble Creek, coupled with habitat improvement by the JSRIP will provide an opportunity to establish a second spawning run for the June sucker in six out of ten years and provide better ability to manage non native fish that prey on the June sucker juvenile fish.

BONNEVILLE UNIT EVOLUTION

As shown in the tables below, the Bonneville Unit water supply has evolved from principally an agricultural water supply project to a municipal and fishery stream supply project. The main four project plans were developed in 1964, 1988, 1998 and 2004. The project plans have been driven by population growth and its demand for municipal water and fishable streams. The amounts shown in the table for fishery water are the volumes used solely for that purpose. Agricultural and municipal flows through rivers that are used for instream minimum flow maintenance or June sucker benefit are not included in the table and are significantly higher than the amounts shown.

Table 1. Total Bonneville Unit Water Supply

Acre-Feet

Year	Agriculture	M&I	Fishery	Total
1964	217,300	79,000	5,000	301,300
1988	180,600	94,750	6,500	281,850
1998	111,800	107,360	44,400	263,560
2004	42,000	157,750	44,400	244,150

Million Cubic Meters

Year	Agriculture	M&I	Fishery	Total
1964	268.0	97.4	6.2	371.6
1988	222.8	116.9	8.0	347.7
1998	137.9	132.4	54.8	325.1
2004	51.8	194.6	50.0	301.1

Although the agricultural water supply has been greatly diminished from the original project vision, funding for water efficiency improvements has benefited some areas more than if Federal delivery systems had been built, with the requisite Reclamation Reform Act reporting requirements and other increased regulations. However, land development, fueled by high population growth rates, has hindered the willingness of some property owners to invest money or participate in major on-farm system improvements. Some Federal funding assistance programs require the property owner to repay grant money received for converting to sprinklers if land is sold and/or converted to municipal use within a specified period of time.

Municipal water users have benefited not only by being allocated greater amounts of water from the project. Federal facilities have enhanced the ability in the future to convey non-project water through facilities, increased supply reliability and the ability to exchange water supplies. Additional Central Utah Project water supplies could delay the need to turn to more costly sources of water. Future water supplies will rely on increasing banking and storage of wet season supplies through local conjunctive use, as well as water recycling. Advances in technology in salinity treatment processes will allow use of Utah Lake water directly for municipal purposes.

In conclusion, the long planning and construction period of the Central Utah Project has required periodic re-evaluation of the project plan to adjust to population growth trends and water needs. Providing funding for local water conservation projects may in some cases provide as great a benefit to water users as constructing facilities to provide a supplemental imported water supply.

EFFECTS OF THE ENDANGERED SPECIES ACT ON WATER RIGHTS AND USES OF WATER IN THE UPPER COLORADO RIVER BASIN

Leslie James[1]

ABSTRACT

The Endangered Species Act (Act) is arguably the most powerful environmental law ever enacted. Since its passage in 1973, it has had far-reaching impacts on rights to use of water for power production of federally owned multiple purpose projects, such as the Colorado River Storage Project (CRSP). Operational changes resulting from implementation of the Act impact not only water and power deliveries, but repayment of the federal investment in the project. In the Colorado River Basin, differing approaches and programs have been established in an attempt to comply with the provisions of the Act. This paper discusses in general terms the Act, provides a description of the current programs and processes underway in the Colorado Basin and discusses costs and impacts in the Colorado Basin.

INTRODUCTION

Colorado River Energy Distributors Association (CREDA)

CREDA is a non-profit Colorado corporation, also authorized to do business in Arizona, formed in 1978 as an association of entities who are long-term contractors for resources of the CRSP. CREDA members are the majority of CRSP firm electric service contractors, and works on their behalf with the federal generating (USBR) and marketing (Western Area Power Administration) agencies. CREDA members serve nearly 3 million consumers in six states: Arizona, New Mexico, Nevada, Colorado, Utah and Wyoming. CREDA membership is quite diverse, with members serving electric loads ranging from over 5,000 megawatts (MW) to 3 MW. CREDA members include state agencies, such as the Colorado River Commission (Nevada) and the Arizona Power Authority (Arizona). CREDA members also include political subdivisions, irrigation and electrical districts, rural electric cooperatives, municipal utilities and tribal utility authorities. CREDA represents its members in regard to rate, legislative (federal), and environmental issues impacting the CRSP. CRSP power customers pay all the costs (with interest) of CRSP power facilities, as well as the costs of CRSP irrigation facilities beyond the ability of the irrigators to pay. This means that CRSP power customers pay more than 95% of the cost of CRSP irrigation facilities. When interest and irrigation assistance are included in project

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repayment, CRSP power customers will eventually repay over five times the power feature investment.[2]

In terms of involvement in environmental issues, CREDA represents its members on the Adaptive Management Work Group (AMWG), a federal advisory committee charged with making recommendations to the Secretary of the Interior with regard to Glen Canyon Dam operations and impacts on the downstream resources. CREDA is also a participant in the Upper Basin Endangered Fish Recovery Implementation Program (RIP), which is the program in the States of Colorado, Utah and Wyoming authorized to recover four species of endangered fish. CREDA is also a member of the National Endangered Species Act Reform Coalition (NESARC), which is a national broad-based coalition interested in achieving reforms to the Act and balance in its implementation.

THE ENDANGERED SPECIES ACT

Description of the Act

In February of 2001, Wyoming Senator Craig Thomas introduced federal legislation intended to amend the Endangered Species Act of 1973 to improve the processes for listing, recovery planning and delisting, as well as for other purposes. His remarks are as relevant today as they were three years ago. In referring to the most powerful environmental law ever enacted, the Senator stated: "the Endangered Species Act has become one of the best examples of good intentions gone astray, and so today I am taking one small step toward injecting some common sense into what has become a regulatory nightmare."[3]

The Endangered Species Act of 1973 followed two previous acts. In 1966, the Endangered Species Preservation Act was passed, which allowed listing of only native animal species as endangered and provided limited protection of listed species. In 1969, the Endangered Species Conservation Act was passed to provide additional protection to species in danger of "worldwide extinction." The 1969 act called for an international meeting to adopt a convention on the conservation of endangered species. In 1973, a conference held in Washington led to the signing of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which placed restrictions on international trade in plant and animal species thoughts to be harmed (or potentially harmed) by trade. Later that year, the Act was passed, which greatly broadened the federal

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[2] Federal Electric Power – Information Concerning the Colorado River Storage Project, GAO Report RCED-90-2FS, October 1989, Tables 3.2 and 3.3, pages 23-25

[3] National Endangered Species Act Reform Coalition (NESARC) website: http//:www.nesarc.org

role in species protection. Although significant amendments were enacted in 1978, 1982 and 1988, the Act has remained virtually unchanged.

It can be argued that the original intent of the Act was to protect species "on the brink" of extinction. That test, however, is subject to broad interpretation and implementation. When the Act was passed, there were 109 species listed for protection. As of May 11, 2004, there were 1,265 on the list, (990 endangered and 275 threatened). As of February 27, 2004, 31 had been proposed for listing, and 256 considered as candidates for listing. Recovery plans have been approved for 1,018 species.[4]

Implementation of the Act

Appendix A contains a glossary of terms that are used in conjunction with implementation of the Act. The Act is administered primarily by the United States Fish and Wildlife Service (USFW), but the National Marine Fisheries Service (NMFS) has responsibility for certain marine fish species. Funding authorization for the Act expired on October 1, 1992, although Congress has appropriated funds in each succeeding fiscal year to keep the program running. The FY 2005 budget request contains $1.3 billion for USFW, with $137 million earmarked for endangered species. It is important to note that these sums do NOT include compensation for any private property owner impacts.

Under the Act, certain species of plants and animals (both vertebrate and invertebrate) are listed as either "endangered" or "threatened" according to assessments of the risk of their extinction. Once a species is listed, legal tools are available to enforce the recovery of the species and protection of its habitat. A species may be classified for protection as "endangered" when it is in danger of extinction within the foreseeable future throughout all or a significant portion of its range. A "threatened" classification is provided to those animals and plants likely to become endangered within the foreseeable future throughout all or a significant portion of their ranges of habitat.

Implementation of the Act can be generally described in three stages: Listing, Recovery Planning and Delisting. Species can be proposed for listing under the Act by a petition process or by a candidate assessment process. Any interested person can petition for the listing of a species. A species is determined to be endangered or threatened due to one or more of the following factors:

- the present or threatened destruction, modification, or curtailment of its habitat or range;
- overutilization for commercial, recreational, scientific, or educational purposes;

[4] U.S. Fish and Wildlife Service, http://endangered.fws.gov, May 11, 2004

- disease or predation;
- the inadequacy of existing regulatory mechanisms; or
- other natural or man-made factors affecting its continued existence.

Once a candidate is identified and there is enough scientific evidence gathered, the relevant federal agency drafts the proposed listing rule for publication in the Federal Register. The proposal includes a 60-day comment period, solicits the opinions of three independent species specialists, the public and federal and state agencies. If the comments warrant listing, the final rule is published in the Federal Register, and the species is added to the list after 30 days.

Once a species is listed, generally the USFW drafts a recovery plan, which includes a description of the current status, the recovery objective and goals, and an implementation schedule. This is a laudable goal, but often lawsuits and inadequate resources delay this part of the process.

As with listing, anyone can petition for downlisting or delisting of a species. If it is determined that the species has reached its recovery goals and protection under the Act is no longer needed, USFW publishes a proposed rule for downlisting or delisting for expert and public review. Following that review, if the rule still stands, it is published in the Federal Register and the species is either removed from or reclassified in the list. After a species is delisted, it must be managed by the state in which it resides according to a monitoring program. The process as described appears fairly straightforward, but actual experience is quite dismal. Of all the species listed, only nine have been delisted.[5]

THE COLORADO RIVER BASIN

Background/River Compacts

As the water supplies in the West became more intensively used in the early part of the twentieth century, the "water wars" began. As a result, western water law evolved through a series of legislative as well as court-related actions. Many of the issues were local in nature; however, they also evolved into interstate and eventually international issues. A great amount of attention focused on the Colorado River because it is one of the most heavily used rivers for multipurpose activities. The Upper Basin states, where the water originates, include Utah, Colorado, Wyoming, and New Mexico. These states used water for agricultural as well as industrial purposes but did not fully use all the water in the river. As the water flowed through Arizona, the southern tip of Nevada, and California (the Lower Basin states), entrepreneurial interests found that they could make the arid climate very productive by diverting water from the Colorado River for irrigation

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[5] Issue Brief, NGA Center for Best Practices, February 2004, citing Endangered Species Bulletin Volume XXIV No. 6

and by rotating crops. Also, large municipal areas such as Los Angeles and San Diego developed in southern California. As the Upper Basin states started to use more water, thereby reducing the water flowing downriver to the Lower Basin states, great debate began in the national Congress. These debates culminated in the Colorado River Compact, which was signed in 1922. The Compact split the water 50-50 between the Upper Basin states and the Lower Basin states. At that time, hydrologists estimated that the Colorado River would produce about 15 million acre feet of water in an average year, therefore 7.5 million acre feet were allocated to the Upper Basin states and 7.5 million acre feet were allocated to the Lower Basin states. In 1956, Congress passed the Colorado River Storage Project Act[6] (CRSP) to provide storage facilities for the Upper Basin states so that they could meet the Compact needs.

The CRSP Act, passed in 1956, envisioned multi-purpose projects. These projects involved building dams to retain water in reservoirs that could be released to meet Compact, municipal and industrial (M&I), and irrigation requirements. As the water was released, electric power and energy could be produced to help pay for the projects. Space also is held in some of the reservoirs to catch floodwaters to minimize their impact on downstream systems, lives, and property. Costs associated with the projects were divided into reimbursable costs and non-reimbursable costs. The "reimbursable" costs were those costs associated with power and water uses. Congress decided that M&I water users would pay for the costs associated with their use, irrigation users would pay "up to their ability to pay", and power users would pay for all of the power facilities plus the irrigation features "beyond the ability of the irrigators to pay". "Non-reimbursable" costs include environmental, recreation and flood control costs, and these are to be paid by the federal government.

The Colorado River Storage Project Features

The CRSP power features include five dams and associated generators, substations, and transmission lines. Glen Canyon Dam is located near Page, Arizona and is by far the largest of the CRSP projects. Glen Canyon power features include eight generators for a total of about 1300 MW, which is more than 70% of the total CRSP generation. Flaming Gorge Dam is on the Green River, a major tributary of the Colorado River, and is located near Vernal, Utah. Flaming Gorge has three units producing about 132 MW of generation. The Aspinall Unit includes three dams and generating plants along the Gunnison River near Gunnison, Colorado. Blue Mesa is the first dam on the river and has two units producing about 97 MW. Morrow Point is the second dam in the series and consists of two generators producing a total of 146 MW. Crystal is the final dam and has one 32 MW generator. Morrow Point and Crystal Reservoirs allow some

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[6] Act of April 11, 1956, ch. 203, 70 Stat. 105

regulation of the river flow so that releases from Crystal can be used to regulate downstream flows as necessary.

The Rio Grande Project in New Mexico and the Colbran Project in Colorado are two small federal projects that were integrated with CRSP into the Salt Lake City Area Integrated Projects (SLCA/IP) for marketing purposes, as they were uneconomical on a stand-alone basis.

In addition to the storage units, CRSP power customers will repay approximately 95% of the irrigation investment in these projects.

- Navajo Unit
- Central Utah Project
- Emery County, Utah
- Florida, Colorado
- Hammond, New Mexico
- La Barge, Wyoming
- Limon, Wyoming/Utah
- Paonia, Colorado
- Pine River Extension, Colo/NM
- Seedskadee, Wyoming
- Silt, Colorado
- Smith Fork, Colorado
- Eden Project, Wyoming
- San Juan-Chama, Colo/NM
- Navajo Indian Irrigation Project

The following projects were added in 1964:

- Bostwick Park, Colorado
- Fruitland Mesa, Colorado
- Savery-Pot Hook, Wyoming

The following projects were added in 1968:

- Animas-La Plata, Colorado/New Mexico
- Dallas Creek, Colorado
- Dolores, Colorado
- San Miguel, Colorado
- West Divide, Colorado

All of these projects except La Barge, Fruitland Mesa, Savery-Pot Hook, San Miguel and West Divide have been completed or are currently under construction.

Endangered Species Impacts on CRSP Power Facilities

CRSP power resources are marketed in a six-state region. Endangered or threatened species within those states, as of May 11, 2004, are: Arizona-54; Colorado-31; Nevada-37; New Mexico-39; Utah-43; Wyoming-15.

Glen Canyon Dam

Glen Canyon Dam is on the mainstem of the Colorado River near the Arizona-Utah state line. It is approximately 15 miles upstream from Lee's Ferry, which is the measuring point for the Colorado River Compact between the Upper Basin states (Utah, Colorado, New Mexico, and Wyoming) and the Lower Basin states (Arizona, Nevada, and California). The dam backs up water forming Lake Powell, which contains approximately 27 million acre-feet of water at the normal water surface elevation. The power plant consists of eight units which can generate approximately 162.5 MW each, for a total output of approximately 1300 MW. The Colorado River Compact requires that 7.5 million acre feet must be released in each rolling ten-year period. The addition of Mexican Treaty water brings this to an average annual release of 8.23 million acre feet per year. Part of the power generated by the dam is used for irrigation pumping and other uses.

In 1978 the USBR began upgrading the eight generating units at Glen Canyon Dam. This upgrade was completed in 1984, and the generation was increased from about 1000 MW to 1300 MW. To fully utilize the unit upgrades would require the maximum release of Glen Canyon to be increased from 31,500 cubic feet per second (CFS) to about 33,200 CFS. This increase raised concerns with downstream users. After discussion with stakeholders, the Secretary of Interior initiated the first phase of the Glen Canyon Environmental Studies.

From 1982 to 1987, the USBR undertook Phase I. These studies were primarily to analyze the impacts of raising the maximum releases on downstream resources (including the endangered Humpback Chub). As scientists are now finding, the Glen Canyon Environmental Studies Phase 1 process did not necessarily follow sound science in that the impact on power and water economics had not been fully explored, and some of the underlying hypotheses of the impacts to downstream resources may not have been correct.

The Secretary then determined that the studies should be continued to address the economic impacts, particularly as they relate to power, and also to collect additional data to substantiate some of the conclusions in the Phase 1 report. The Glen Canyon Environmental Studies Phase 2 was initiated in 1989. In July 1989, the Secretary of Interior announced the start of an environmental impact statement (EIS) on the operation of the Glen Canyon Dam. The EIS was completed and the Record of Decision signed in October 1996. The result was that Glen Canyon operations were changed to reflect a revised flow regime; approximately one-third of the generating capacity was lost due to changed operations. The cost of the EIS was approximately $104 million, and was funded by CRSP power revenues (received by WAPA from CRSP power customers from long-term contracts).

CREDA participates on the Federal Advisory Committee charged with making recommendations to the Secretary of the Interior as to operations of Glen Canyon Dam pursuant to the Record of Decision and underlying laws. Funding for the program (Adaptive Management Program) is primarily through power revenues. On October 27, 2000, President Clinton signed the Interior Energy and Water Appropriations bill, which includes language (section 204) capping the amount of CRSP power revenues that can be used for the Adaptive Management Program, at $7,850,000, subject to inflation. The current budget is over $10 million.

In April of 2000, it was determined that due to hydrologic conditions and resulting from a 1994 USFW biological opinion, a low flow summer experiment would be undertaken. The experiment included high spike flows in May and September, with low flat flows (8,000 CFS) all summer. The purpose was to gain information regarding Humpback Chub conditions. The low, flat flows had a severe impact on power generation, requiring WAPA to purchase replacement power on the open market in order to meet contractual obligations to the CRSP customers. The cost of this replacement power was $22 million! The cost of the experiment was over $3 million, also funded by CRSP power customers.

In April 2002, the Adaptive Management Work Group (AMWG) reached agreement on a two-year program of experimental flows, intended to improve sediment conditions and improve conditions for the endangered Humpback Chub through a program to adverse conditions for the trout, which are competitors and predators. An Environmental Assessment and Record of Decision were completed in December 2002. Preliminary results indicate that fluctuating flows are beneficial to the Chub, as they adverse Brown and Rainbow Trout spawning conditions. The Trout are a significant predator of the Chub.

Flaming Gorge Dam and the Aspinall Unit

A recovery program for endangered fish (the RIP) was established in 1988 for an initial 15 year period to help recover four endangered fish in the Upper Colorado Basin. Power customers currently fund about 60% of the base research / study program, which now requires about $2.1 million of power revenues per year. The program requires CRSP power customers to fund approximately $6.0 million/year for a base program, with credits toward repayment, and about $17 million of a $100,000,000 capital program to implement the recovery programs. In addition, changes in Flaming Gorge and Aspinall generation as a result of the Biological Opinions cost power users $2 to $5 million per year.

In July 2000 scoping meetings for a Flaming Gorge EIS began. The purpose of the EIS is to assess the effect of flow recommendations on endangered species. Power customers will be required to fund this EIS, anticipated to cost $3 million. A draft EIS is expected in mid-2004.

Recovery Goals for the four endangered fish species were published and finalized in September 2002. The Recovery Goals establish population parameters required for downlisting and delisting of the species. The Goals cover upper and lower Colorado Basin populations. The Humpback Chub Goals are the subject of recent litigation filed March 31, 2004. It is unclear what, if any, financial, legal or other impacts this litigation may have.

Since June of 2000, the RIP participants were involved in discussions with USFW regarding their proposed flow recommendations for the Gunnison River. Flow recommendations were finalized for the Gunnison River in July 2003.[7]

In early 2004, the USBR began an EIS process on the operations of the Aspinall Unit to avoid jeopardy. This process is expected to take four years and cost several million dollars. Of significant concern with this process is to ensure the scope is narrow and that sound science is used to develop the alternatives. Argonne National Labs has done some modeling work for WAPA that indicates the flow recommendations can be assisted with water that is already at risk of spill; thus alleviating the need for additional adverse dam operational changes. Because this "same" water is the subject of state and federal litigation, it is unclear how the litigation and EIS processes and outcomes will be coordinated.

SUMMARY

Based on information provided by WAPA, the *direct* costs to the USBR and WAPA of endangered species impacts through 2001 total $228,644,852[8] for the CRSP. Approximately $50,000,000 of this amount is treated as reimbursable from power customers, meaning they are directly borne by the power customers in the form of increased power rates. However, both reimbursable and non-reimbursable costs have a direct impact on WAPA's Basin Fund as well as its ability to make timely CRSP repayment to the U.S. Treasury, and ultimately have an impact on power rates. These costs do NOT include additional impact costs borne by CRSP power customers for replacement power required as a result of changed operations and experimentation programs. These costs have resulted in a severe cash flow situation for WAPA, which resulted in their reducing energy deliveries to their customers. In addition, they have been unable to make returns of principal and interest payments to the U.S. Treasury, which ultimately impacts federal project repayment of water storage and delivery projects in the Upper Basin. In addition to the direct financial impacts on individual power customers throughout the six state CRSP area, the current implementation of ESA also places at risk the capability of the CRSP to satisfy the growing demands for water in the Colorado River Basin.

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[7] http://www.r6.fws.gov/crrip/doc/GunnCoflowrec.pdf

[8] Colorado River Storage Project, USBR and WAPA, Combined Glen Canyon Environmental Studies and Other Environmental Costs, January 22, 2003

APPENDIX A: GLOSSARY OF ENDANGERED SPECIES ACT TERMS

Biological opinion - A document that is the product of formal consultation, stating the opinion of the USFW on whether or not a Federal action is likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat.

Consultation - All Federal agencies must consult with the USFW (or NMFS) hen any activity permitted, funded, or conducted by that agency may affect a listed species or designated critical habitat, or is likely to jeopardize proposed species or adversely modify proposed critical habitat. There are two stages of consultation: informal and formal.

Critical habitat - Specific geographic areas, whether occupied by listed species or not, that are determined to be essential for the conservation and management of listed species, and that have been formally described in the Federal Register.

Endangered - The classification provided to an animal or plant in danger of extinction within the foreseeable future throughout all or a significant portion of its range.

Habitat - The location where a particular taxon of plant or animal lives and its surroundings (both living and nonliving) and includes the presence of group of particular environmental conditions surrounding an organism including air, water, soil, mineral elements, moisture, temperature, and topography.

Listed species - A species, subspecies, or distinct vertebrate population segment that has been added to the Federal lists of Endangered and Threatened Wildlife and Plants as they appear in sections 17.11 and 17.12 of Title 50 of the Code of Federal Regulations (50 CFR 17.11 and 17.12).

Recovery - The process by which the decline of an endangered or threatened species is arrested or reversed, or threats to its survival neutralized so that its long-term survival in nature can be ensured.

Species - From Section 3(15) of the Act: "The term 'species' includes any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature."

Source: http//:endangered.fws.gov, Region 3 Endangered Species Home Page

SURVIVING THE DROUGHT: SHARING SHORTAGES ON THE SAN JUAN RIVER

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John R. Simons[2]

ABSTRACT

In 2003, water users along the San Juan River in New Mexico were confronted with a situation that they had never before experienced since the construction of Navajo Dam in the 1960's: the possibility that the water supply would be less than the projected demand. The potential water shortage was the result of several years of drought, highlighted by the extremely low water year in 2002. In response to this, Reclamation and the State of New Mexico initiated discussions with the ten major water users in the basin in September 2002.

Several major, unresolved issues clouded the initial discussions and the potential for legal battles pitting farmers against the Endangered Species Act; Indians against non-Indians; and state water law against federal responsibilities, loomed large.

In spite of all this however, the group, after nearly ten months of negotiations, cooperatively developed a set of recommendations for the operation of Navajo Reservoir and administration of the San Juan River for 2003[3]. The plan included unique shortage sharing methods and collaborative water marketing concepts, which resulted in all users receiving a sufficient water supply in 2003.

INTRODUCTION

In 2002, the San Juan River Basin, along with the rest of the southwestern United States, suffered through its worst drought on record. That year, Navajo Reservoir, constructed by Reclamation in the 1960's, received only 15% of its 30-year average annual inflow. Releases made throughout the summer to meet downstream demands, including maintaining adequate flows through designated critical habitat area for two endangered fish, severely depleted the content of Navajo Reservoir. Faced with this bleak outlook, and at the request of the Navajo Nation, Reclamation and the New Mexico Interstate Stream Commission (NMISC) initiated discussions with the ten major water users along the San Juan River in New Mexico in September 2003.

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[3] The Shortage Sharing Agreement documents for 2003 and 2004 can be found at: www.usbr.gov/uc/wcao/water/projects/navshort.html

THE PLAYERS

Water use on the San Juan River in New Mexico is divided into two distinct user groups: those who have an authorized use or have a subcontract with the United States for Navajo Reservoir storage water, and those who divert a direct-flow water right on the San Juan River via a state permit. In order to develop a cooperative plan for water use on the San Juan River, both groups had to be represented. Representatives from the following groups were invited to participate in the development of a plan for water use in 2003 (Note: the (*) indicates those entities who are authorized users of Navajo Reservoir storage water. All other users have direct-flow rights on the San Juan River below Navajo Dam):

- Jicarilla Apache Nation *
- Navajo Nation (Navajo Indian Irrigation Project*, and Hogback and Fruitland Irrigation Projects)
- City of Farmington
- Public Service Company of New Mexico – San Juan Generating Station*
- Arizona Public Service Company – Four Corners Power Plant
- BHP Billiton (BHP) (water right holders for the two power plants listed above)
- Hammond Conservancy District – Hammond Irrigation Project*
- Bloomfield Irrigation District – Citizens Ditch
- Farmers Mutual Ditch Company
- Jewett Valley Ditch

Also involved in the discussions were the U.S. Fish & Wildlife Service (Service), the Bureau of Indian Affairs (BIA), and the San Juan River Basin Recovery Implementation Program (SJRIP). The uses represented by the various participants symbolized the competing uses throughout the West that have been battling over water issues the last few decades – irrigation, municipal, industrial, Tribal, and environmental. Recreational uses, both in the reservoir and downstream of the dam, were not represented in the discussions; however those interests were considered in the development of the recommendations.

THE ISSUES

The unprecedented drought of 2002 drained reservoir supplies throughout the west, and Navajo Reservoir was no exception. With a severely drawn down reservoir, and a less-than-average snowpack forecast for the 2002-2003 winter, the San Juan River Basin faced a gloomy 2003 water year. This uncertain future is what brought the players to the table. Even beyond the bleak water supply outlook however, several big, unresolved issues clouded the initial discussions. These issues included the ongoing adjudication of all water rights on the San Juan River, the Navajo Nation's unsettled water right claims, the absence of measurement structures on most diversions and the lack of administration on the river, many differing legal opinions regarding water right permits, diversion amounts, and diversion records, and a general mistrust of the state and federal government. Throw in a trans-basin diversion and two endangered fish species, and you have a recipe for disaster.

It was clear from the outset that many of these unresolved issues would have to be set aside if a plan were to be developed and implemented in 2003. Some issues however, could not be ignored and would have to be factored into any plan that was developed. These included flow recommendations for the endangered fish, restrictions on minimum reservoir releases, the physical and operational limitations of the Main Headworks of the Navajo Indian Irrigation Project (NIIP), Indian Trust Assets, and compliance with the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA).

Two endangered fish, the Colorado pikeminnow and the razorback sucker inhabit the San Juan River below Navajo Dam, and since 1999, Reclamation has been operating Navajo Reservoir to meet flow recommendations developed by the San Juan River Basin Recovery Implementation Program (San Juan RIP)[4]. The basis of the flow recommendations is to mimic the natural hydrograph. The recommendations provide flow variability considered necessary to create and maintain habitat for pikeminnow and razorback sucker. The recommendations integrate hydrology, geomorphology, habitat, and biology to define flow magnitude, duration, and frequency for the spring runoff period and base flows for the non-runoff periods. While the projected inflow to Navajo Reservoir in 2003 was too low to provide for a spring peak release, the non-runoff period target base flow through the designated critical habitat still had to be met. This meant that as tributary inflows to the San Juan River downstream of Navajo Dam dropped off, releases from the dam had to be increased in order to ensure sufficient flows were maintained in the critical habitat.

As mentioned above, Reclamation has been operating Navajo Dam to meet the flow recommendations since 1999. However, to fully implement the flow recommendations in the future, when full water development has occurred in the basin, releases from the dam would have to be lower than the historical minimum releases (500 cfs) in order to provide for high volume peak spring releases. In 1999, Reclamation issued a Notice of Intent to prepare a draft Environmental Impact Statement (EIS) on the operation of Navajo Dam to meet the flow recommendations for the endangered fish. The draft EIS, released in September 2002, contained a preferred alternative that included minimum releases from the dam of 250 cfs. The draft EIS also concluded that impacts could occur to the trout fishery with releases from the dam of 250 cfs during the irrigation season.

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[4] Holden, P.B. 1999. Flow recommendations for the San Juan River. San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, NM. 187 pp.

In addition, the San Juan Flyfishing Federation had filed suit against Reclamation in 1996, prior to Reclamation initiating a winter low flow test designed to study the effects of 250 cfs release from Navajo Dam. The two sides eventually agreed to a Stipulation and Settlement Agreement[5] whereby releases could not be reduced below 500 cfs permanently without first complying with the provisions of NEPA.

Another consideration that had to be included in the plan was the physical location of the NIIP headworks with respect to the reservoir water surface level. The NIIP headworks, with a capacity of 1,800 cfs and located near the left abutment of Navajo Dam, takes water from the reservoir and delivers it through the Main Canal system approximately 40 miles to the Navajo Nation's farm enterprise located south of Farmington and operated by Navajo Agricultural Products Industry (NAPI). The top of the NIIP headworks is at elevation 5,990 feet above mean sea level. As such, the NIIP headworks defines the bottom of the active capacity of Navajo Reservoir. Section 11 of Public Law 87-483[6], directs Reclamation to, in the event of a shortage, apportion shortages to authorized users on a pro-rata basis. If the reservoir water surface level were to drop below elevation 5,990 feet, the capacity of the NIIP diversion would be reduced, eventually to zero, which would result in a 100% shortage to NAPI. Depending upon your interpretation of P.L. 87-483, this could result in a 100% shortage to all authorized uses of Navajo Reservoir water, including the endangered fish. Thus, it was imperative that water surface elevation 5,990 feet be protected in order to avoid this situation.

The economic factor of the two coal fired power plants and the related coal mine also had to be considered. Early in the discussions, it became apparent that the companies could not afford to have their water supply reduced. Thus, water marketing concepts were included in the discussions.

A trans-basin diversion also exists in the system. The San Juan-Chama Project diverts water from San Juan River tributaries upstream of Navajo Reservoir into the Rio Grande Basin. Because of minimum bypass flow requirements that are in effect at the three San Juan-Chama diversion points, and with the anticipated low inflow to Navajo Reservoir, the project diversions would be severely limited in 2003. There were also some questions as to how Section 11 of P.L. 87-483 was to be applied to the San-Juan Chama Project. Still, with the San Juan Basin water users looking at possible shortages to their water supply, the trans-basin diversion to the Rio Grande had to be addressed.

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[5] San Juan Flyfishing Federation vs. United States of America, Bruce Babbitt, Secretary of Department of the Interior, No. CIV 95-1476 JP

[6] Public Law 87-483, 76 Stat. 96, June 13, 1962, Navajo Indian Irrigation Project and San Juan-Chama Project, Initial Stage.

THE METHOD AND PROCESS

Once the group had identified the issues, the next formidable task was to develop a method as to how shortages would be 1) calculated, and 2) apportioned to the participating entities. The iterative process of apportioning shortages also took into account water marketing strategies that were employed.

Calculating Anticipated Shortages

Section 11 of Public Law 87-483 directs Reclamation to apportion shortages to entitled users of Navajo Reservoir storage water, on a pro-rata basis, in the event shortages are anticipated. This section of the Act also provides a method to apportion shortages to Navajo Unit contractors. This method was used as a foundation on which the 2003 Shortage Sharing Agreement was based upon.

To calculate anticipated shortages, the fundamental comparison of supply versus demand had to be made. The supply was estimated and took into account both prospective runoff and available water in storage in the reservoir. Historically, Reclamation has used the Most Probable Inflow Forecast, generated by the Colorado Basin River Forecast Center, in the development of the Navajo Reservoir Annual Operating Plan. The Most Probable Forecast is the best estimate of stream flow volume that can be produced given current conditions and based on the outcome of similar past situations. There is a 50 percent chance that the stream flow volume will exceed this forecast value. There is a 50 percent chance that the stream flow volume will be less than this forecast value. Because of the uncertainty inherent in water supply forecasts, and the concerns expressed by the Navajo Nation regarding NIIP's vulnerability of getting 100% shorted if the reservoir were to go below 5,990 feet elevation, Reclamation utilized the more conservative Minimum Probable Forecast in 2003. With this forecast, there is a 90 percent chance that the stream flow volume will exceed this forecasted value. There is a 10 percent chance the stream flow volume will be less than this forecast value. The Minimum Probable Forecast was used to help water users plan for potential shortages. In theory, using this approach, predicted annual shortages would be higher in the early spring months when more variability and unpredictability exists regarding snowpack amounts. As the season progresses, the uncertainty regarding snowpack and the resulting runoff lessens, resulting in the range of forecasted inflow amounts (minimum probable to most probable) being less variable. If the forecasts were correct, the minimum probable forecast amount would increase to meet the most probable forecast amount, which would result in the anticipated shortage amounts to be reduced.

Along with the supply, the demands of the various users had to be determined. Depending upon the use, the diversion demand amounts were determined based on a combination of historical use, direct flow rights, contracts with the Secretary of the Interior, and/or contracts or agreements with other parties. The demands were, in some cases, negotiated amounts that took into consideration differing opinions of the parties as to the demands and rights to divert water under existing conditions, facilities, rights, permits, contracts and applicable law.

The following water diversion demands for specified projects or uses were recognized for 2003:

	Amount (acre-feet)	Rate (cfs)	Period
Navajo Indian Irrigation Project	204,000	--	3/15-11/15
Hammond Irrigation Project	26,700	90	4/01-10/31
San Juan Generating Station	24,200	--	1/01-12/31
Four Corners Power Plant	31,000	--	1/01-12/31
Minor Jicarilla subcontracts	4,670	--	1/01-12/31
City of Farmington	15,000	--	1/01-12/31
Citizens Ditch	--	160	4/01-10/31
Farmers Mutual Ditch	--	110	4/01-10/31
Fruitland Irrigation Project	--	100	4/01-10/31
Jewett Valley Ditch	--	32	4/01-10/31
Hogback Irrigation Project	--	170	4/01-10/31

In addition, the agreement recommended that Reclamation not make a spring peak flow release for endangered fish purposes in 2003, and that the target base flow for endangered fish be maintained at 500 cfs (the target recommended in the Flow Recommendations), provided a shortage is not in effect.

The parties also recommended that, in the event of a shortage, Reclamation limit its annual San Juan-Chama Project diversions for 2003 to an amount equal to 107,500 acre-feet less the percentage shortage calculated by Reclamation. This volume (107,500 acre-feet) represents the average annual diversion of the project. Though not a signatory to the Recommendations, the San Juan – Chama Contractors Association provided a letter of support for the agreement.

The group developed a computer model to calculate anticipated shortages using the most recent Minimum Probable forecast, the available water supply in Navajo Reservoir, and the anticipated demands from the various users and uses. This model was updated twice a month as new forecasts became available. Using the Minimum Probable Forecast and the anticipated demands for water, the model ran through the entire year of Navajo Reservoir operation. If the model caused the reservoir level to drop below elevation 5,990 feet (bottom of active storage, delineated by the intake structure for the NIIP anytime during the irrigation season (March through early November), this indicated that a shortage would occur. The model would then proportionally allocate that shortage to all users and uses based upon their respective demands for the year. As a result of decreasing or shorting the demands of all users and uses, the reservoir level would not drop below elevation 5,990 feet. As the inflow forecasts and actual water levels in Navajo Reservoir changed, so did the anticipated shortage amount.

Apportioning Shortages to Users

Once the shortage volume had been calculated, the next step was to apportion the shortage to the various users on a pro-rata basis. A unique aspect of this agreement was that several methods of taking shortages were developed and made available to the various users. Users could elect to have shortages applied to their instantaneous diversion rate, their annual diversion volume, or their calculated depletion volume.

If the operational model discussed above indicated that the reservoir water surface level would fall below elevation 5990 feet at any time during 2003, then Reclamation would calculate the amount of shortage to the diversion demands that must occur to prevent the projected water surface level in the reservoir from falling below elevation 5990 feet. An iterative process was used to determine the percentage shortage that, if applied proportionally to the various users and uses, would result in reductions in water uses on the San Juan River in a total amount equal to that of the calculated amount of shortage. The shortage percentage was applied to the following demands: (1) the annual 2003 diversion demand amounts for the Navajo Indian Irrigation Project, the San Juan Generating Station, the Four Corners Power Plant and the minor Jicarilla Apache Nation subcontracts as listed above; (2) an annual irrigation depletion demand of 37,000 acre-feet in the aggregate for the Citizens Ditch, the Hammond Irrigation Project, the Farmers Mutual Ditch, the Fruitland Irrigation Project, the Jewett Valley Ditch and the Hogback Irrigation Project; and (3) the 500 cfs target minimum base flow in the San Juan River below its confluence with the Animas River for the time period for which the base flows may be shorted.

The water users would determine the time schedules for bearing their share of any shortage during 2003. If the amount of water already diverted by any user during 2003 exceeded its resultant diversion limitation, then the user would have to cease diverting water for the remainder of 2003.

The endorsing parties agreed that the diversions for the Citizens Ditch, the Hammond Irrigation Project, the Farmers Mutual Ditch, the Fruitland Irrigation Project, the Jewett Valley Ditch and the Hogback Irrigation Project shall be reduced to effectively short the annual irrigation depletion demand under each ditch or project by the same percentage shortage, if any, as calculated by the model. Prior to the irrigation season, each ditch or project chose whether it would reduce its irrigation diversion rate or its irrigation season in order to meet its commitment to reduce irrigation depletions during 2003 if a shortage were to occur. All downstream ditches chose the depletion shortage method, which meant that the end date for the period during which the ditch or project may divert water for irrigation uses during 2003 would be moved forward in time from October 31 until the percentage reduction in irrigation depletion matches the same percentage shortage as calculated by Reclamation. To determine a revised end date to the irrigation season, the following percentages indicating the distribution of the annual irrigation depletion by month were used: 5 percent for October; 12 percent for September; 19 percent for August; 22 percent for July; 19 percent for June; 13 percent for May; and 10 percent for April. The revised end date could be adjusted further to provide credit for any irrigation depletion demand forgone as a result of delaying the start date of the irrigation season past April 1 or as a result of ceasing diversions during the irrigation season. In order for a ditch to receive credit for irrigation depletion demand foregone as a result of ceasing, the ditch had to: (1) provide Reclamation and the State Engineer with one-week advance notice of the dates during which diversions will cease; and (2) cease all diversions for any purposes during the dates specified, not to be for a duration of less than one week. Irrigation depletion reductions for partial months were estimated assuming a constant daily irrigation depletion rate within each month. Diversions by ditches for delivery to municipalities, industrial users, domestic water user associations and stock uses could continue outside the irrigation season whether the season is shorted or not.

Water Marketing Concepts

Recognizing the power plants' desires to have a full water supply, even in the event of a shortage, the group incorporated a water marketing concept into the Shortage Sharing Recommendations.

The Jicarilla Apache Nation, pursuant to the Jicarilla Apache Tribal Water Rights Settlement Act of October 23, 1992 (Settlement Act), is the owner of certain water rights in Navajo Reservoir and has the right to market such water. The Settlement Act entitled the Jicarilla Apache Nation to 33,500 acre-feet of Navajo Reservoir supply. Since the Settlement, only a small portion (770 acre-feet) of this water had been contracted for.

Initially, the group defined normal water use demands as those demands that had been historically delivered from Navajo Reservoir or diverted from the San Juan River. Since the majority of the Jicarilla Settlement Act water had not previously been put to beneficial use, it was not considered a "normal demand" and so was not included in the demand calculations. Therefore, in order to utilize the Jicarilla Nation's legal ability to market water (no other endorsing party had that ability or authority), a water supply would have to be derived from the "normal demand" pool. The Navajo Nation, who benefit from the power plants through both royalties from the plants and employment of tribal members, had a vested interest in keeping the power plants fully operational. As such, a plan was developed that would have made water available from within the NIIP diversion amount limitation for 2003 to alleviate any shortages to the diversion demand amounts identified for the San Juan Generating Station, the Four Corners Power Plant and the mines. The NIIP forbearance plan, as it was called, was not received well from NAPI, who viewed it as a water grab that benefited big business and hurt Native Americans. As a result, the Navajo Nation struck all references to such an arrangement in their formal resolution to approve the Shortage Sharing Recommendations.

Without an emergency water supply, the companies were not interested in signing any agreement, and the cooperative process that had led us so close to developing a plan was on shaky ground. At the urging of the companies, the Jicarilla Apache Nation requested Reclamation to take a position on the determination of "normal demand" as it applied to the Nation's Settlement Water in Navajo Reservoir. After some discussion and deliberation, Reclamation determined that this water had the same priority of any other Navajo Reservoir contract water, and therefore could be utilized in 2003 if a use was identified. Obviously, a use had been identified – emergency supply water for the companies. One issue still remained however; the Jicarilla Settlement Act water had not undergone consultation under Section 7 of the ESA, and therefore did not have a depletion associated with it. Without a depletion, compliance with ESA would not be possible. After more discussions with the group, a marketing concept was developed that called for an incremental shortage, above and beyond the original shortage, to be applied proportionally to irrigators, including NAPI, in order to provide the necessary depletion coverage needed for the power plants' emergency supply water. The power plants agreed to mitigate the irrigators for this incremental loss of water in the form of money. A fund in the amount of $1,120,000 was established to mitigate the effects to the water supply of any added increment of shortage caused by actual diversion of water under the subcontracts. Of the total amount, $120,000 was set aside to be distributed on a pro-rata basis to the irrigators at the end of the irrigation season, regardless of whether any water had been delivered under the subcontracts or not. The remaining $1,000,000 was set aside to be distributed based on the amount of the supplemental water actually used by the power plants under the subcontracts.

THE RESULTS

Basing the anticipated shortages on the minimum probable inflow forecast resulted in fairly high predicted shortages early in the year. The April forecast predicted a 35% shortage. As forecasts were updated, the anticipated shortages dropped, but shortages were still predicted. Forecasts were updated every two weeks from April through September.

Users incorporated various strategies in anticipating and dealing with anticipated shortages. NAPI planned their operations around their estimate of a 10% anticipated shortage. As a result, their diversions from the reservoir were 178,567 acre-feet, or 87.5% of their identified normal demand for 2003.

Some downstream ditches elected to delay the start of their irrigation season, thereby gaining depletion "credits" in anticipation of shortages. Some ditches also stopped diverting for a week during the irrigation season, again to gain depletion credits.

The power plants chose to defer taking any shortages until the end of the year. Using this approach, the power plants could withhold from using any of their Jicarilla Apache subcontract water until absolutely necessary.

In the end, thanks in large part to the willingness of diverse water user interests to work together, as well as some timely rain events that occurred in September, the anticipated shortage never materialized into an actual shortage, consequently most water users received their full supply, and others, who had voluntarily reduced their use in anticipation of a shortage, were not greatly impacted. The power plants did not take delivery of any of their Jicarilla Apache Nation subcontract water, and as a result, paid only the initial $120,000 out of their mitigation fund. Releases from Navajo Reservoir, including diversions to NIIP totaled 520,000 acre-feet for the year, compared to 669,900 acre-feet in 2002 when no such reservoir management/river administration plan was in place.

THE FUTURE

While no major shortages were realized in 2003, with an inflow to Navajo Reservoir in 2003 of 402,000 acre-feet (39%), reservoir storage was further depleted, to an all-time post-fill low. The group of endorsing parties was convened in August 2003, to begin working on a similar agreement for 2004. Plans to conserve as much water as possible over the winter of 2003-2004 were immediately developed. Recommendations were presented to Reclamation, the Service, and the SJRIP, and as a result, releases from the dam were reduced to 250 cfs beginning November 3, 2003. With additional delays in the Navajo Reservoir Operations EIS, the group was faced with similar operational limitations at Navajo Dam that they had confronted in 2003.

While some minor changes were made to the plan developed for 2003, the 2004 version maintains the same cooperative philosophy employed in 2003 -- a philosophy that has resulted a diverse group of competing water interests coming together for the good of all to resolve their differences in a meeting room and not a court room.

USING "SURPLUS" WATER TO MEET DOWNSTREAM ENVIRONMENTAL NEEDS IN SYSTEMS CONSTRUCTED FOR WATER AND POWER BENEFITS

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ABSTRACT

The Colorado River Storage Project consists of large Federal dams and reservoirs on the Upper Colorado River Basin. The largest of these are the Glen Canyon Dam in Arizona, Flaming Gorge Dam in Utah and Blue Mesa Dam in Colorado. The authorizing legislation requires that these dams be operated for purposes related to water development and power production. In recent years the operation of these facilities has been the subject of intense environmental review. Downstream of these dams are endangered fish species, sport fisheries, white water recreation and national parks or monuments.

One way of reconciling the conflicts that have surfaced is to use surplus water or "water at risk of spill." Based on forecasts, water is identified beyond what is needed to fill reservoirs, meet water delivery obligations and generate electrical power. This amount of water is then patterned in terms of timing, magnitude and duration to meet downstream environmental needs. Hydrological/operational studies have shown that "water at risk of spill" can meet the biological flow recommendations for endangered fish species for the Gunnison River below Blue Mesa Dam. Moreover, "water at risk of spill" forms the underpinnings of beach and habitat building opportunities below Glen Canyon Dam. These examples provide evidence that important environmental needs may be accomplished in water delivery systems without changes to the legal authorities of dams constructed for water development purposes.

INTRODUCTION

Operations for Water Management at Bureau of Reclamation Dams

Operation of dams, reservoirs and powerplants along the Colorado River and the Upper and Lower Colorado River Basin are set forth in the 1922 Colorado River Compact, 1968 Colorado River Basin Project Act (CRBPA) and the 1970 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (Operating

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Criteria). The Bureau of Reclamation (Reclamation), an agency under the U.S. Department of the Interior (DOI), operates the dams and reservoirs using the Operating Criteria.

Two Colorado River Basin Projects are Glen Canyon Dam and powerplant and its reservoir Lake Powell, along with Hoover Dam and powerplant and its reservoir Lake Mead. The CRBPA introduced the concept of equalizing Lake Powell and Lake Mead and directs the Secretary of the Interior to "to maintain as nearly as practicable, active storage in Lake Mead equal to the active storage in Lake Powell..." Additionally, minimum releases from Lake Powell are 8.23 million acre-feet (maf) per year. When Lake Powell end-of-year (EOY) storage is greater than that of Lake Mead, water will be released from Lake Powell in excess of the 8.23 maf/yr minimum.

Statistically, the hydrologic spring season runoff that contributes the highest water inflow into Lake Powell begins in May, peaks in June and continues through July. Occasionally, when spring runoff occurs, Lake Powell is at its maximum water surface elevation of 3710.6 feet. The maximum water surface elevation is the highest acceptable water surface from a computed routing of the inflow design flood through the reservoir under established operating criteria with all factors affecting the safety of the structure considered.[3] When Lake Powell reaches its maximum water surface elevation and additional spring runoff inflows continue, additional releases above the powerplant capacity of 33,100 cfs occur and the service spillways operating at a maximum release of 275,000 cfs are used. Very rarely, inflows exceed both powerplant and spillway capacity. In this case, outlet works or bypass tubes are opened and water is released through both the spillway and the bypass tubes. Glen Canyon Dam released water through both the spillway and its two bypass tubes each operating at a maximum of 15,000 cfs in the spring of 1984 during a major flood event.

Spill Water

Spill water is defined as excess water that cannot be stored in the applicable reservoir because of limited storage capacity relative to inflow and that is greater than the flow-through capacity of the power plants. Spilled water would be released either through bypass structures or spillways.

Creation of a New Idea: Spill Water to Meet Environmental Purposes

The passage of the Grand Canyon Protection Act (GCPA) of 1992 set the stage for a conflict regarding the authorized purposes of Glen Canyon Dam. The act requires the Secretary of Interior to operate the dam ". . . in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon national Recreation Area were

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[3] http://www.usbr.gov/main/library/glossary/#maximumwatersurface

established, including, but not limited to natural and cultural resources and visitor use." In apparent contradiction to this is language in the same section of that act which states that this should be done "in accordance with . . . existing law" and in the next section: "The Secretary [of Interior] shall implement this section in a manner fully consistent with and subject to . . . provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968."

Subsequent to the passage of the GCPA, DOI completed a final Environmental Impact Statement (EIS) on the operation of Glen Canyon Dam. For the purposes of sediment conservation in the Grand Canyon, the preferred alternative included a "Beach, Habitat Building Flow" (BHBF). This operation consisted of creating a man-made flood in the Grand Canyon to mobilized stored sediment on the river bottom and deposit it elsewhere in the canyon in order to create beaches and sandbars. According to the EIS, a BHBF would only occur during dry hydrological conditions.

A political conflict began to develop as concept of a BHBF moved forward. Even as a national media event developed around a test of the concept of a BHBF that occurred in March of 1996, Colorado River Basin States were lobbying DOI and contemplating legal action over the use of a BHBF-type flow to conserve Grand Canyon sediment. The legal conflict arises because the acts mentioned above do not authorize the operation of Glen Canyon Dam for the purposes described in the GCPA. Specifically, spill or bypass of the power plant at Glen Canyon Dam, is specifically to be avoided. (CRBA, Sect. 602 (a) (3) (iii). Apparently, Congress had handed the Secretary of Interior a dilemma as large as the Basin itself.

A resolution to this paradox was also developing however. The Bureau of Reclamation was given a charge by the Secretary to work out a compromise. The compromise was this: a BHBF would be allowed, but only in wet hydrological conditions, ". . . by utilizing reservoir releases in excess of power plant capacity required for ***dam safety purposes***." (emphasis added). This means that a BHBF, a flow regime that spilled or bypassed the power plant, would by allowed as long as a spill was already eminent or at least a strong possibility due to a full reservoir and high inflows.

Shortly after the formation of the post-EIS Adaptive Management Group (AMG), an Ad Hoc Committee was formed by the AMG to work out the specific details of when a BHBF might be triggered by hydrology. This was a creative enterprise which developed the idea that a forecast of Lake Power inflow could be used as a "hydrological trigger" for a BHBF.

Historically, Reclamation responded cavalierly to forecasts of high inflow that occurred early in the winter. Due to the large statistical error associated with early forecasts, Reclamation chose to either ignore the high inflow forecast or minimally increase releases. As the forecast season progressed and the runoff season started, Reclamation would pay greater attention to these forecasts and increase the water release schedule through Glen Canyon power plant. This operational approach still leaves Reclamation open to surprises, specifically when inflows to Lake Powell are especially high or are not predicted by the forecast.

A new approach, the approach developed by the Ad Hoc Committee, was to pay closer attention to the forecasts of inflow into Lake Power which began in January of each year. If forecasted inflow is higher than what can be put through the power plant during the runoff period, there is a "*risk of spill.*" Therefore, water can be used to produce a BHBF: some of the water likely to spill is "managed" to meet the purposes of the GCPA. In other words, water that is not expected to be used for power production or for water storage is used for environmental purposes.

Transference of the New Idea: Spill Water Use to Meet Environmental Purposes at Other CRSP Dams

Aspinall Unit: The Aspinall Unit located on the Gunnison River in Colorado consists of three dams and powerplants—Blue Mesa, Morrow Point and Crystal. The dams were authorized along with the Glen Canyon and Flaming Gorge Dams by the 1956 CRSP Act. The purposes of these dams are the same as Glen Canyon Dam: to store Upper Colorado River Basin water, to ensure delivery of compact water to the Lower Colorado River Basin and to generate electrical power. Blue Mesa reservoir has the largest water storage capacity in Colorado. While electrical generation at the Aspinall Units is considerably less than at Glen Canyon Dam, the Aspinall Units still provide much of the ability of the CRSP units to follow hourly changes in electrical demand.

Two developments have recently occurred regarding claims for water in the Gunnison River, potentially impacting the operation of the Aspinall Units. First, the Black Canyon of the Gunnison National Park (Park) is situated below the Aspinall Unit. The National Park Service (NPS) was granted an unquantified water right for the Park in a court decree on March 6, 1978. A water right claim was filed on behalf of the NPS on January 21, 2001. A NPS water right would be achieved through operation of the Aspinall Unit.

Also on the Gunnison River, the U.S. Fish and Wildlife Service developed flow recommendations for endangered fishes (Colorado pikeminnow *Ptychocheilus lucius*, humpback chub *Gila cypha*, bonytail *Gila elegans*, and razorback sucker *Xyrauchen texanus*) that identify critical flows to be achieved in the lower Gunnison and upper Colorado River in Colorado.

On April 2, 2003, the State of Colorado and DOI signed an agreement to protect water for the Black Canyon. The agreement stated that based on the May 1 inflow forecast, any water allocated as water "which would fill and spill" at Blue Mesa would be protected water for the Black Canyon. In other words, this agreement is compatible with the concept of spill water developed for Glen Canyon Dam seven years earlier.

On July 3, 2003, the U.S. Fish and Wildlife Service and the Upper Colorado Recovery Implementation Program (UCRIP) participants agreed to flow recommendations for the Gunnison River which allowed some flexibility in meeting these recommendations.

As a result of the spill language of the Black Canyon settlement agreement and the flexibility of the Gunnison River flow recommendations for endangered species, Western commissioned Argonne National Laboratory to scientifically determine the impact on Black Canyon resources of spill water. Western's interest was this: if the use of "water at risk of spill" was used to meet the flow recommendations and produce benefits for identified resources in the Black Canyon, it would significantly reduce the impact of the flow recommendations and water right on power and water interests.

Results of Argonne's Study: Using historical water gage data below the Aspinall Units, Reclamation constructed more than twenty years of anticipated Aspinall operations under current operating rules. From this, Argonne constructed an Aspinall operation that utilized spill water in wet hydrological conditions. Argonne constructed four different spill scenarios, under the assumption that water at risk of spill may not be used the same way each time it becomes available. For example, in some wet years, it will be desirable to create the maximum peak possible with available water. In other years, the duration of a lower peak may be of greater advantage to fish and other resources.

For Argonne's Black Canyon study, Argonne analyzed the impact of the spill water concept on the resources the National Park Service submitted with its original water filing. These were flows that would: (1) support fish and aquatic life; (2) preclude vegetation establishment in the active channel; (3) control riparian vegetation through drowning; (4) transport sediment; (5) enhance visitor experience and appreciation of the river; (6) entrain and transport sediment; (7) serve as spawning cues for fish; and (8) maintain channel forming processes.[4]

In a separate study, Argonne evaluated the possibility of using water at risk of spill from the Aspinall Unit to meet FWS flow recommendation and other endangered fish flow recommendations from other authors.[5] The same

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[4] LaGory, Lonkhuyzen, Hayse & Tomasko, *An Evaluation of Proposed Aspinall Unit Operations to Achieve National Park Service Objectives in the Black Canyon of the Gunnison National Park*, Environmental Assessment Division, Argonne National Laboratory, January 2003.

[5] LaGory, Tomasko & Hayse, *Evaluating the Effects of Aspinall Unit Release Strategies on Endangered Fish Habitat in the Lower Gunnison River*, Environmental Assessment Division, Argonne National Laboratory, August 2003.

hydrological scenarios were used as in the Black Canyon. In this study however, the impacts of spill water were measured against flow recommendations for endangered fish species.

With respect to the flow recommendations for endangered fish, Argonne concluded that ". . . all [of the spill water] scenarios would achieve the FWS recommendation[s]. . . " when the years used to analyze the flow recommendations are those years which formed the basis of the recommendations (1978 – 1997). Only one "spill water scenario achieved all of the flow recommendations if additional drier years are added (1998 – 2000).

For the Black Canyon, Argonne concluded that the impact of different spill water scenarios "would be relatively small" and "similar to the impact of the NPS water filing."

This is a somewhat surprising result—that the impact on key Black Canyon environmental resources of spill water scenarios is similar to NPS' original filing. After all, the original claim seemed to require quite a different set of flows. This surprising result is explained by noting that the vast majority of the water released through the Aspinall Units is released for other purposes. The spill water concept, or for that matter the NPS' original claim, is water "at the margin": its impact is overwhelmed by the delivery of water for other purposes throughout the year. Spill water, when judiciously managed, can never-the-less add substantially to the accomplishment of environmental purposes.

Argonne's study provides hopeful information regarding the utility of transferring the spill water concept to the Aspinall Units.

Flaming Gorge Dam: In September, 2000, the Upper Colorado Recovery Program and the F&WS approved flow recommendations for the Green River to aid in the recovery of endangered fish species in this river. Reclamation began the development of an EIS on the operation of Flaming Gorge Dam in an attempt to meet these flow recommendations while maintaining the authorized purposes of this CRSP dam.

Western is currently analyzing whether the spill water concept can be used to meet the recovery needs of endangered fish in the Green River below Flaming Gorge Dam.

CONCLUSION

Historically, Reclamation has taken aggressive action to avoid being unprepared for conditions that would warrant a spill or bypass at the CRSP facilities. However, in recent years, the concept that spill water can be beneficially used to meet environmental purposes has been a thriving idea in negotiations related to the operation of Glen Canyon Dam. Further, it seems clear that this concept can be beneficially transferred to the Aspinall Units as a way to meet endangered species needs and other environmental purposes without creating significant adverse impacts to electrical power production and water storage. Given these successes, the concept of spill water may also be beneficially applied to meeting endangered fish needs through the operation of Flaming Gorge Dam.

ECONOMIC IMPORTANCE AND ENVIRONMENTAL CHALLENGES OF THE AWASH RIVER BASIN TO ETHIOPIA

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ABSTRACT

Ethiopia's agriculture currently depends on rainfall with limited use of water resources. Highly variable rainfall, frequent floods and droughts, and limited storage capacity continue to constrain the ability of the country to produce reliable food supplies in a country that is relatively rich in water and land resources. The Awash Valley has been the major focus of medium and large scale irrigated agriculture developments since the 1950s, and presently has over 70 percent of Ethiopia's non-traditional irrigation. In addition, there are traditional and non-traditional small-scale irrigation systems within the valley, and major dams to improve the management of water for agriculture and produce hydropower have been constructed. Furthermore, this economic activity has produced major secondary benefits to the valley area. With the continuing decline of the productivity of the rain-fed agricultural lands and the anticipated doubling of food demands over the next two decades, improved water management in agriculture, including irrigation is of paramount importance. Numerous authors, policy makers and other observers have stressed the very high-unrealized potential for intensification of agriculture through irrigation in Ethiopia. Yet, apart from the Awash Valley, limited development has occurred in irrigation development. Like much of the highlands of Ethiopia, mixed livestock cropping system predominate in the upper basin, whereas pastoralism was traditionally and currently practiced in the middle and lower reaches. The major irrigated agriculture and water resources have occurred in the middle valley and, more recently, towards the lower reaches. Other issues associated with the water management in the middle and lower basin is soil salinization, water contamination and increased water-borne diseases, and poor design leading to water loss through leakage and evaporation. Expanding irrigation threatens wetlands, and conflicts over access to water constrain smallholder farmers and pastoralists, which depend on livestock herds for their existence. Because communities lack skills and institutions to

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manage common property resources, water resources, basin/watershed and irrigation management infrastructure quickly fall into a state of disrepair. In the lower valley, desertification is a serious threat.

INTRODUCTION

Overview

At approximately 50% of the GDP, agriculture, most of it based on rain fed smallholder system and livestock, is by far the largest part of the economy and growing on average 5% per year. Despite this, the country could still face more than 6 million tons of cereal deficits by the year 2016 (UK Trade and Investment 2004). Ethiopia has an estimated 3.7 million hectares of irrigable land, yet only about 200,000 hectares (5.4%) is presently irrigated and only provides approximately 3% of the country's food crop requirements.

Description of the Basin

Most of the irritation schemes in Awash Basin have good reputation in irrigation efficiency and the irrigation efficiency in Awash River Basin varies from 30 to 55 %. Based on physical and socio-economic factors the Awash Basin is divided into Upper Basin (region above Koka Dam), Upper Valley (region between Koka Dam and Awash National Park), Middle Valley (region between Awash National Park and Gewane town) and Lower Plains (Figure 1a and 1b). The mean annual flow is around 2200Mm^3 at Tendaho. The highland part of Awash Basin gets adequate rainfall as compared to the Middle and Lower Valley. The source of Awash River is the central plateau in the west of Addis Ababa. Awash River starts at an elevation of about 3000 m a.s.l. It flows northeastwards along the rift valley to the Afar triangle where it terminates in Lake Abe near Djibouti at an elevation of 250 m.a.s.l (Abate 1994). The Awash River basin covers a total land area of 110,000 km^2 and serves as home to 10.5 million. The mean annual surface water resource of the Basin is in order of 4900 M m^3, utilizable 3850 M m^3 and currently diverted for irrigation is 2250 M m^3.

The Awash River Basin is the most intensively utilized river basin in Ethiopia due to its strategic location, access roads available land and water resources. However, the basin suffers from severe environmental degradation, annual flooding, improper utilization of land, water resources, socio-economic constraints, poor agricultural practices, and low yielding and community health problems.

Flooding

The Awash River basin is mostly located in the arid lowlands of Afar Region in the north- eastern part of Ethiopia. It frequently floods in August/September following heavy rains in the eastern highland and escarpment areas. A number of tributary rivers draining the highlands eastwards can increase the water level of the Awash River in a short period of time and cause flooding in the low-lying alluvial plains along the river course. Certain areas, which frequently, almost seasonally, get inundated, are marshlands such as the area between the towns of Debel and Gewane in the vicinity of Lake Yardi and the lower plains around Dubti down to Lake Abe in Afar Region. The third area, which often floods, is about 30 kilometers north of Awash town in the vicinity of Melka Werer.

Water Reservoirs

Though Ethiopia has substantial hydropower potential it has one of the lowest levels of per capita electrical consumption in the world. There are three functional dams in Awash River Basin, Aba Samuel (1.5 GWh/year) commissioned in 1939, Koka (110 GWh/year) commissioned in 1960, Awash II (165 GWh/year) commissioned in 1966, and Awash III (165 GWh/year) commissioned in 1971. Koka was built on the upper Awash for hydropower generation and irrigation development downstream. The dam has served for four decades. In the coming years five additional dams are proposed to be built for hydropower generation and irrigation development in the basin.

Hydrological Balance

The available water from rainfall in the basin is 39845 (Mm^3/yr), 72 % of the rainfall (28383 Mm^3/yr) is lost through evapotranspiration, 18 % (7386 Mm^3/yr) runoff and 10% (4074 Mm^3/yr) is rechargeable water..

Deterioration of Watersheds

As with other parts of Ethiopia, the upper Awash basin, and its major tributaries have been subjected to major environmental stress. The demand for natural resources by the high and fast growing population remains a major challenge to effective agricultural and forestland management. The high pressure on forest resources in particular, has led to the exploitation of fragile watersheds and ecosystems that have resulted in loss of vegetation and subsequent soil erosion in the lower part of the Awash River Basin (Kinfe 1999).

Addis Ababa, the capital of Ethiopia with three million inhabitants and by far the largest city in the country, is located in the upper Awash basin. There is very little capacity for wastewater treatment; therefore, wastewater is discharged directly into the natural watercourses of the Akai River, which eventually joins the Awash River. The Akai River is an important water source for small farm operations in and around Addis producing vegetables and livestock fodder.

This presents a significant health hazard from the microbiological contamination to the surface and groundwater, and concerns that heavy metals are accumulating soils. Few rigorous investigations have been undertaken, but nitrate levels are reported to be above 10 mg/l in the surface water, and according to Biru (2002) and Itanna (2002), arsenic (As) and zinc (Zn) are measurably higher in the soils irrigated by the Akai River. Akaki River is one of the tributaries draining Addis Ababa City to the Awash River.In the middle and lower Awash the water-related health hazards are malaria and schistosomiasis, which are reported to be increasing in prevalence and severity. Basic requirements such as water supply, sanitation and health facilities are poor (Waltainformation 2004).

A major health concern in much of the middle and some of the lower Awash River Basin is high levels of fluorides in the groundwater, which is used as a major source for drinking water (Gizaw 1996; Tadesse et al., 1998). The fluoride risks come as people drink groundwater, other wise the Awash River water is free of fluoride. High concentrations of fluoride occurring naturally in groundwater water are a major source of fluoride intake. It has long been known that excessive fluoride intake carries serious toxic effects. The long-term use of high-fluoride drinking water results in both dental and skeletal fluorosis, which is found in populations in the Middle and Lower Awash, and the Rift Valley Basin.

Ecology and the Environment

The single overriding factor in the ecology of the Awash basin is the rapid and continuous increase in population and the adverse effects on the resources of the basin, in particular, on the rapid erosion and degradation of the upland soils. The high indication of the sediment load is a result of deforestation and less ground cover in the highland of the upper basin.

Development of large scale irrigation projects without functional drainage systems and appropriate water management practices have led to a gradual rise of saline groundwater tables in the Middle Awash Region (Tadesse and Bekele 1996). Shallow and saline ground water table has created surface salinity on the once productive lands. As a result, a large productive area has got secondary salinization, which is brought up by faulty irrigation practices. In general, implementation of appropriate sub-surface drainage projects with proper leaching practices is effective and efficient reclamation methods for sustainable agricultural production under the Middle Awash irrigated conditions (Aabegaz and Tadesse 1996).

Desertification

Manifestations of desertification in Awash River Basin include accelerated soil erosion by wind and water, increasing salinization of soils and near-surface groundwater supplies, a reduction in soil moisture retention, an increase in surface runoff and stream flow variability, a reduction in species diversity and plant biomass, and a reduction in the overall productivity in dry land ecosystems with an attendant impoverishment of the human communities dependent on these ecosystems. The lower Awash River Basin is under severe land degradation and desertification. As the few trees are removed for charcoal and fuel wood, salt patches and salt accumulation is appearing over large areas killing the vegetation cover. In both Middle and Lower Awash River Basin Prosopis Juliflora, an aggressive exotic plant species, is spreading at alarming rates in alluvial fertile land, around homesteads, and in drainage canals and roads. Juloflora believed to have allelopathic potential on indigenous vegetation.

Cropping Pattern and Crop Production

In 1988 the irrigated area in the entire basin was estimated to be 69 000 ha. Currently the state farms control 90% of the irrigated area, private farmers control about 7% and the remaining 3% of the irrigated area is more-or-less abandoned due to salinity build up water logging from shallow ground water. The state farms are generally found in the Middle and Lower sections of the valley and the major irrigators in the upper valley are the Ethiopian Sugar Corporation Ethiopian Share Enterprise (ESC) and Ethiopian Horticultural Corporation Share Enterprise (HDC). Historically sugar and cotton have been the major crops grown in Middle and Lower Awash Valley.

Fruit production has been increasing since about 1999, with the bulk of fruit and vegetables sold in the local market in all river Basins in Ethiopia. The production of high value flowers and vegetables for export has recently been introduced in the Rift Valley Lake Basin and Awash River basin. In 2001 and 2002 the exported vegetables has increased by 95 % as compared to 1998 (Table 1). Among this 45 % of the flower exported comes from the Awash River Basin. As the external market opportunity is growing several private flower enterprises are emerging (Table 2). In the lower valley of the drier areas where moisture is critical summer cropping pattern is common such as cotton. However in the Upper Valley the highest percentage of cropping is occupied with sugar cane (Table 3). Ethiopia is completely self-sufficient in cotton. This crop holds significant opportunities for export. Existing textile industries demand approximately 50,000 tons of lint cotton annually. In addition, there are good prospects for exporting lint. Opportunities for production and processing of cotton in Ethiopia are significant. The prevailing cropping pattern in the upper Valley is sugar cane (74%), in the middle Valley cotton (82%) and in the lower Valley cotton (75%).

Table 1. Domestic fruit, vegetable, maize and factory products in Awash Basin (quintals = 100kg).

Year	Fruits	Vegetables	Maize	Factory products
1998	63,818	719	314	9,727
1999	378,421	2,383	5,833	1,314
2000	382,971	1,866	533	5,278
2001	404,818	1,888	578	0
2002	395,020	1,101	376	5,104
2003	335,353	368	268	2,293

Source: Ethiopian Horticultural Corporation Share Enterprise (Annual Report 2003)

Table 2. Flower & vegetable exports (quintals).

Year	Flowers	Vegetables
1998	1,470	23,803
1999	547	30,588
2000	470	33,407
2001	30,695	374,124
2002	1,150	374,124

Source: Ethiopian Horticultural Corporation Share Enterprise (Annual Report 2003).

Table 3. Production and sales of cane sugar in Ethiopia from the Awash Basin.

Year	Total production (tonnes)	Total sales (tonnes)
2000	250,867	257,483
2001	251,368	253,055
2002	261,041	234,800
2003	263,209	307,476

Source: Annual Report of Ethiopian Sugar Industry Support Center Share Company (2003).

The Middle and Lower Awash is one of the major cotton producing areas of Ethiopia. However, during the last decades most of the agricultural land has been abandoned as a result of inherent soil salinity and saline shallow ground water. In most of the irrigation project development drainage system were not built. Thus the irrigated land did not change over time and expanded, as salinity became a major threat for development of agricultural land (Table 4 and 5). Cotton produce after ginning is supplied to local textile industries.

Table 4. Area planted under cotton (ha).

Producer	1996/97	1999/98	1998/99	1999/00	2000/01	Average
Lower Awash	5,450	5,625	5,955	5,645	4,117	5,358
Middle Awash	5,153	5,268	4,789	1,667	5,407	4,457
Upper Awash	1,000	1,000	1,000	1,000	1,000	1,000

Source: RATES 2004

Table 5. Yield of seed cotton (tonnes/ha).

Producer	1996/97	1999/98	1998/99	1999/00	2000/01	Average
Lower Awash	1.5	1.4	1.6	2.0	2.0	1.7
Middle Awash	2.9	2.2	2.0	3.5	2.9	2.7
Upper Awash	2.1	2.1	2.1	2.1	2.1	2.1

Source: RATES 2004

Livestock

The Awash valley has historically been a main gateway for the caravan trade between the coast and the highlands of Ethiopia to Djibouti and Berbera. At present, the strategically important official import and export trade activities of the country take place through the pastoral areas of the Afar and Somali regions. Cross-border trade with neighboring countries is also an important aspect of the economic life in these pastoral areas of the country. In 2001, the total population of the Afar region was 1.24 million while that of the Somali region was about 3.9 million. In addition to the large human population, these regions also account for a large number of the livestock population of the country. The Afar region, which is part of Middle and Lower Awash River Basin , has 3.6 million cattle, which is 7.4% of the national total, while the region's sheep and goat populations are 2 million (7.8%) and 3 million (13.8%) respectively. Besides this, the Afar region has 192,872 pack animals, i.e., 3 % of the national total, and 871,832 camels, which is 27 % of the national total (Reporter 2003). The livestock population in Afar Region in Middle and Lower Awash Basin has showed an increasing trend starting from 1998 (Figure 2). This was mainly due to several water points developed in the region, which once was a critical issue in the region. Currently great attention is paid for the pastorals development to increase, feed resources, watering points, health and marketing.

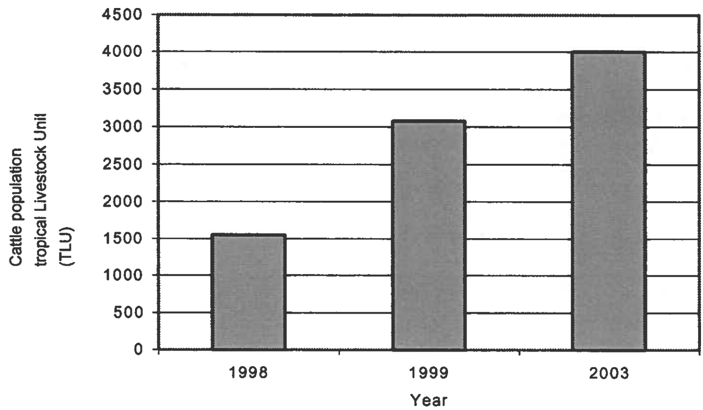

Figure. 2. Cattle population in Middle and Lower Awash Valley (Afar Region).

SUMMARY & CONCLUSIONS

The Awash Basin has the most developed water system in Ethiopia, and because of these developments the basin has been a major component of the Ethiopian economy for the past four decades.

The original major investments in the basin were to produce sugar and cotton. Sugar continues to be a major crop, and the cropped area and production is increasing. However, cotton production has declined. Fruit and vegetable crop production for the domestic market is rapidly growing in the valley, and in the past few years the production of high-value vegetable and flowers has emerged.

The basin is now essentially a closed basin and the water resources may even be over-appropriated. Also, many factors, including increasing population, migration into the basin, further expansion of irrigated areas, inappropriate management practices of the upper catchment's, and so forth, are threatening the sustainability of irrigation in the basin.

The environmental condition of the valley is a cause for concern. Loss of vegetation in the highlands is further accelerating the erosion rates in the upper Awash and its tributaries, which, among other things is reducing storage capacity of major reservoirs. Also in the highlands, irrigation of raw-eaten vegetables with untreated wastewater from the expanding urban center of Addis Ababa is creating a health threat.

Salinization of soils has resulted in loss of productive lands, especially in the lower parts of the basin.

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Figure 1a. Map of Ethiopia showing the approximate watersheds, main rivers and lakes.

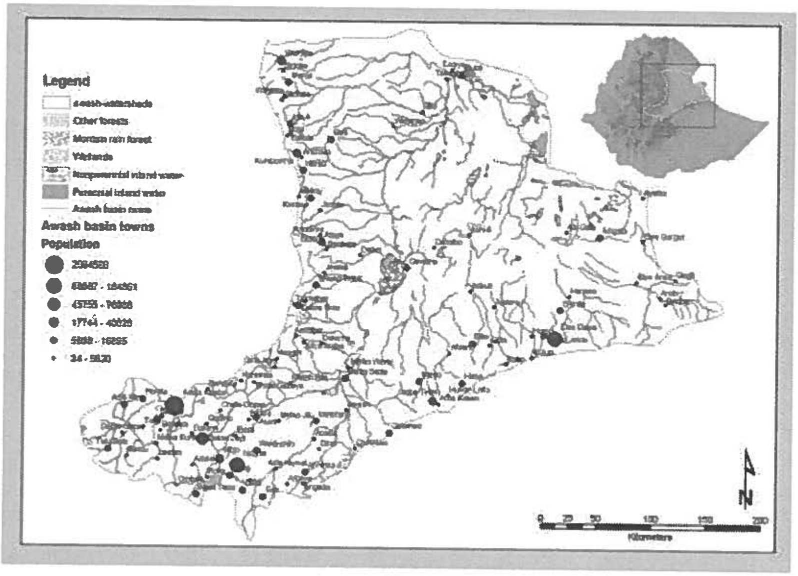

Figure 1b. Awash Basin map.

ENVIRONMENTAL FLU SHOTS
PROACTIVE MANAGEMENT TO AVOID CRISIS MANAGEMENT

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W. Russ Findlay[2]
Tennille Flint[3]

ABSTRACT

To avoid the suffering that accompanies influenza, your best bet is to get a flu shot. A moment of discomfort prevents serious suffering down the road. It is also so in the world of environmental compliance. Proactive management of water development that anticipates environmental concerns can prevent explosive environmental situations and protect all interests.

Proactive measures can provide for cheaper, faster and better project implementation in compliance with the Endangered Species Act (ESA). It is better to protect a species and its habitat as early as possible, to avoid ESA listing. Where a species is listed, a Recovery Program has great benefit in recovering the species at a lower cost and with reduced public controversy.

The Clean Water Act requires mitigation for wetland impacts. However, early planning and integration of environmental considerations within the project design can reduce or even eliminate the impacts and thus the required mitigation.

The requirements of the National Environmental Policy Act (NEPA) are often blamed for project delays and increased project costs. NEPA compliance that includes integration of project design is ultimately the faster and cheaper road to successful project implementation.

Exploration of these three laws reveals that in environmental compliance, an ounce of prevention is worth a pound of cure.

INTRODUCTION

Increasing public concern for the protection of the environment in the middle of the 20th century led to the enactment of a host of environmental laws in the 1960s and 1970s. In general, these laws impose certain requirements upon the Federal government and private industry, rather than upon individual citizens. Thus, the Federal government had to add a completely new layer to its project management

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process to achieve newly necessary environmental compliance. Decades later, the Federal government and other entities, including water users, recognize the importance of environmental compliance but still wrestle with how to achieve it in a cost-effective and timely manner.

THE ENDANGERED SPECIES ACT

Congress passed the Endangered Species Act (ESA) in 1973. One of its principal provisions is that all Federal agencies are required to undertake programs for the conservation of endangered and threatened species, and are prohibited from authorizing, funding, or carrying out any action that would jeopardize the existence of a listed species or destroy or modify its "critical habitat." Before any Federal agency can begin a project or provide funds or permits for a project that may affect a listed species or its critical habitat, they are required to consult with the U.S. Fish and Wildlife Service (FWS) or the National Marine Fisheries Service (NMFS) and determine ways to avoid jeopardizing these species.

Stories abound regarding compliance with the ESA. Some describe landowners deliberately killing populations of endangered plants to avoid the Act's restrictions. Others involve heavy handed bureaucrats confiscating property and destroying the livelihoods of unsuspecting citizens. Most of these stories are simply hearsay, and often further investigation shows that they were less controversial and one-sided than they were purported to be. More typical ESA compliance efforts involve a good deal of cooperation and compromise. Most entities faced with the choice of litigation, legislation, or cooperation, choose cooperation and compromise. It is usually quicker, less costly, and produces decisions that facilitate better and faster project implementation.

Between 1987 and 1991, approximately one percent of proposed projects were ultimately rejected because of insurmountable threats to endangered species (Bryant, 2002). Approximately 20% of projects that are referred for consultation with the U.S. Fish and Wildlife Service are modified to protect listed species. These modifications include provisions for acquisition, restoration, and revegetation of habitat; establishment of trust funds, and other mitigation or conservation measures.

The ultimate purpose of the ESA is to bring about the recovery of endangered and threatened species. However, it is a highly controversial and often criticized statute; less than one percent of all listed species have recovered under the ESA and widespread opposition across the United States has slowed the process for listing species under the Act (Bryant, 2002).

The Klamath River Basin

The Bureau of Reclamation (Reclamation) has diverted water from the Klamath River since 1907. Much of this water is used to grow crops on historically arid lands. The Klamath Basin has become a national focal point for controversy regarding the ESA. The diversion of water to irrigation projects threatens the existence of coho salmon, shortnose sucker, and Lost River sucker.

Coho salmon were listed as threatened under the ESA in 1997. The Lost River and shortnose suckers were listed as endangered in 1988. The FWS and NMFS issued biological opinions in 2001 that recommended water levels in the basin's lakes be increased to protect the suckers, and flow rates in the river to be increased to protect the coho salmon. This occurred during a period of record drought. Water supplies were cut off to 1,200 farmers within the Klamath Irrigation Project. Farm production was lost, the economy was disrupted, and several farms went bankrupt. There is no doubt that most parties involved in this controversy would have liked a more amicable process for finding solutions to the area's problems.

To make things more complicated and controversial, subsequent findings by scientists have questioned the need for providing these flows. The scientific community has not had sufficient time to arrive at definitive habitat parameters needed by the listed fish. Because of questions on the science and political pressures, flow recommendations have not been consistent or well accepted. The result of a situation like Klamath is the inability to successfully implement a project (in this case, the delivery of irrigation water) while requiring significant expenditures over a number of years to reach a solution to the problem.

It must be recognized that the Klamath situation developed over a relatively short period of time and communication, consultation, and coordination efforts take time. We can learn from this situation that the key to successful ESA compliance is being willing and able to start early and spend significant time on proactive coordination and management efforts. Two types of proactive efforts are 1) the establishment of recovery programs where species are listed, and 2) the establishment of conservation agreements to promote assistance to a declining species, thus preventing a requirement for protection under the ESA.

The June Sucker Recovery Implementation Program

In 1986, the June sucker, a native species found only in Utah Lake and its tributaries, was listed as endangered under the ESA. In 1994, the U.S. Fish and Wildlife Service issued a jeopardy opinion which stated that continued operation of the Provo River Project would likely jeopardize the existence of the June sucker.

In this case, managers had the foresight to establish workgroups and teams whose purpose was to resolve conflict early in the process before managers were left with very few options in dealing with ESA controversies. These teams aided in implementation of the Reasonable and Prudent Alternative and eventually achieved the 2002 establishment of the June Sucker Recovery Implementation Program. The program's goal is to recover the June sucker while allowing for the continued operation of existing water facilities and future development of water resources. Participants have developed working relationships based on trust, and credibility. Once these working relationships are established, recommendations to managers can be made in a timely manner and prevent "train wrecks." Teams are made up of representatives from Federal and state agencies, municipalities, water users, sportsmen's, and environmental groups. Other entities are also encouraged to participate.

The Columbia Spotted Frog

Working to improve population parameters of a species before it becomes listed is a very good practice. It avoids the "emergency room" approach to species recovery. By starting early in the process, researchers are given time and latitude to arrive at sound biological recommendations, and managers are given time to understand the issues and consequences of various actions.

The Columbia spotted frog, *Rana luteiventris*, ranges from southeast Alaska through Alberta, Canada, and into Washington, Idaho, Wyoming, Montana, and disjunct areas of Nevada and Utah. In Utah, isolated Columbia spotted frog populations exist in the West Desert and along the Wasatch Front. Unfortunately, habitat degradation and loss have led to declines in many of these populations, especially those along the Wasatch Front, precipitating the inclusion of the species on the *Utah Sensitive Species List* maintained by the Utah Division of Wildlife Resources.

Utah populations of the Columbia spotted frog are currently managed under an inter-agency Conservation Agreement between Federal and state natural resources agencies in Utah. The goal of the Conservation Agreement is to ensure the long-term conservation of the Columbia spotted frog within its historical range in Utah. The Conservation Agreement established a mechanism for the recovery of the Columbia spotted frog through inter-agency cooperation, coordination of conservation efforts, and development of recovery priorities. As guided by the Conservation Agreement, protection measures such as habitat acquisitions, negotiation and purchase of conservation easements with private landowners, habitat improvements, and others have been completed or are ongoing (UDWR web site).

Several years ago, the spotted frog was petitioned for listing. In large part because of efforts under the Conservation Agreement, the U.S. Fish and Wildlife

Service did not find that the species warranted listing. In general, Reclamation's Provo Area Office is finding that ongoing, proactive communication and coordination among state and Federal agencies serves to enhance the protection of sensitive species such as the spotted frog without causing undue delays in water project implementation and operation.

THE CLEAN WATER ACT

Efforts to protect the Nation's waterways began in 1948 with the passage of the Federal Water Pollution Control Act. The provisions of this act authorized development of comprehensive programs for eliminating or reducing pollution of interstate waters. Amended in 1972, a national goal was established to restore and maintain the chemical, physical, and biological integrity of the nation's waters. In 1977, the Act was again amended, and at this point became known as the Clean Water Act (CWA).

The 1972 amendments strengthened and modified the regulatory provisions of the CWA. The most common regulatory mechanisms encountered are Section 402, which monitors pollutant discharges into waterways and manages polluted runoff, and Section 404, which limits destruction of wetlands.

Section 402 of the 1972 amendments established the National Pollution Discharge Elimination System (NPDES). The release of any foreign substance into waters of the United States usually requires a permit. In most cases, the Environmental Protection Agency (EPA) has delegated this permitting authority to the states.

Section 404 of the CWA deals with discharge of dredge and/or fill materials into navigable waters. The Army Corps of Engineers (Corps) "may issue permits after notice and opportunity for public hearings for the discharge of dredged or fill material into the navigable waters at specified disposal sites."

The nature of the permit depends on several aspects of the project. The project is examined for the type and amount of wetlands or waters involved, the attributes of the project, other environmental impacts, the scope of the project, and the public interest.

If the impacts are determined to be minimal then the project may not need an individual permit. Projects that may have significant environmental impacts, involve substantial public interest, or do not qualify for nationwide permits require an individual permit with substantial data requirements. Applying for an individual permit requires a detailed project description, wetlands documentation, 404(b) (1) guidelines compliance, mitigation, NEPA compliance, other agency involvement, and public involvement.

Mitigation may be required under nationwide, regional, or individual permits. Mitigation is the avoidance and minimization of adverse impacts to wetlands, and replacement of wetland areas that are unavoidably impacted. Mitigation efforts are classified in order of preference. Avoidance is always preferred, and other mitigation strategies should be implemented only after that it has been shown that avoidance and minimization are not possible (Environmental Laboratory, 1987).

The permitting process can at times seem overwhelming and burdensome, which is why it may seem tempting to circumvent the whole system. However, when agencies and parties cooperatively work on project design and implementation, a permit can often be issued in a timely manner.

The Central Utah Water Conservancy District (District) in Utah recently needed to dredge the reservoir basin behind Vat Diversion Dam, a small dam located on the Duchesne River. Sediment had accumulated behind the dam in significant amounts which measurably reduced the capacity of the reservoir. Recognizing the probability of needing a 404 permit, a meeting was set up among the Corps, the District, and Reclamation before construction began. This meeting was conducted on site, with all parties professing willingness to communicate and listen. As the District described their proposed work plan, it appeared the project would require an individual permit, a timely process that could take several months. The District's original proposal was to push the deposited sediment with a bulldozer into an upland area above the reservoir. Through discussion with the Corps representative it was determined that by slightly modifying the project design the need for a permit could be eliminated. Rather than pushing the sediment around, which would constitute placement of fill, the District could use a backhoe to pick up the material, place it into a dump truck, and transport the material out of the jurisdictional area and place it in an upland area. The purpose of the project could still be accomplished, but a 404 permit would no longer be required.

When possible, maintaining flexibility in project design can make the difference in the type of permit, or whether a permit is required. With early communication and coordination, the Corps is able to assist in project design and implementation that will allow for a timely and successful completion while still protecting the water resources.

A site visit as part of this process is strongly recommended. When the Corps was first contacted regarding a siphon replacement project at Arthur V. Watkins Dam adjacent to the Great Salt Lake, the phone discussion led to a preliminary conclusion that a permit would likely be required. When the site visit was conducted, however, the Corps had the opportunity to see the project setting and observe that there would be few environmental effects. As a result, it was determined that a permit was not required.

Permits are often required, however, and can include one or more special conditions. Discussion with the Corps may provide clarification regarding why special conditions were stipulated. Ultimately, however, proceeding with the project under the permit implies acceptance of those conditions, even if the permittee disagrees with them. Compliance with such special conditions, no matter how trivial, is essential to successful and timely project completion. A party was recently found to be in violation of its 404 permit by not having a copy of the permit on site. The violation seemed like a minor matter, but still resulted in lost time and money. Hours were spent within the office dealing with the matter, representatives from both the Corps and project proponent traveled to the site to discuss the matter, and a degree of trust and credibility was lost between the project proponent and the Corps, which proceeded to scrutinize the project more carefully to ensure compliance. Every condition is important and must be met. For example, silt fences must be maintained, and revegetation and rehabilitation must be completed. Compliance with these conditions not only ensures protection of the environment but also allows the project to be completed in a timely and efficient manner.

Violations of the CWA may not only result in lost time and project costs but can result in substantial fines. For example, a major retail chain in May 2004 was fined over $3 million for CWA violations. At 24 construction sites in 9 different states the retailer failed to obtain the required 404 permits, failed to establish a runoff control plan, and failed to take adequate measures to prevent storm water discharge (Associated Press, May 12, 2004). The largest fine on record was in 2003 when a company was required to pay a $34 million penalty for violations that led to the release of 1.45 million gallons of petroleum products into the environment.

While the process of obtaining permits may seem cumbersome, and a common philosophy is "It is easier to ask forgiveness then ask permission," this is not a prudent approach for compliance with the CWA. Alerting the appropriate agency early in project planning will only result in a better project. Permits can be obtained quickly, or the project can be modified to eliminate the need for a permit. It is not always true that the permitting process will result in additional time and costs. Rather, it is attempts to avoid compliance that often produce additional project costs and delays.

THE NATIONAL ENVIRONMENTAL POLICY ACT

Since its enactment on January 1, 1970, the National Environmental Policy Act (NEPA) has acquired an arguably undeserved reputation as being synonymous with project delays and higher project costs. Among the many environmental laws enacted by the Congress in the 1960s and 1970s, NEPA stands out for its requirements forcing Federal agencies to 'think before they act'—to calculate and disclose the impacts of their actions before they make publicly transparent decisions to implement such actions. Planning ahead is not a strength of the human race, and so right off the bat, NEPA requires us to do things we don't like to do.

However, evidence suggests that properly executed NEPA compliance does not slow down a project or add significantly to its overall costs. To the contrary, it appears that delays and costs are more frequently associated with attempts to circumvent or short-cut the NEPA process. NEPA compliance, begun early in the project planning stages, with analyses closely related to project design, not only doesn't cause unnecessary delays, but can lead to successful and timely implementation of better and cheaper projects.

Just how long does NEPA take, anyway? A study by the Federal Highway Administration (FHWA) and the Lewis Berger Group examined both the real schedule implications of the NEPA process in relation to a total project, and the individual factors influencing the time required to complete a NEPA process. In reviewing 30 years of data on FHWA NEPA compliance, this study found that it took, on average, 3.6 years to complete an Environmental Impact Statement (EIS). Surprisingly, this was only 28% of the total time needed to complete an entire project, which averaged 13.1 years. While this study did not speculate on the non-NEPA related factors that might delay project approval and implementation, these numbers suggest that in general, a review of how well the NEPA process is integrated into program and project management could yield useful information on streamlining the process.

The Department of Energy (DOE) tracks data on a quarterly basis for the cost and completion times associated with NEPA documents. In the third quarter of Fiscal Year 2000, DOE data showed that the average completion time for three EISs was 28 months, and the average completion time for 20 Environmental Assessments (EAs) was 14 months. While these data did not include information on total time for project completion, they did include feedback from NEPA document preparers as to successes and failures. Among the items cited as beneficial to the NEPA process were early stakeholder involvement, good community involvement including a toll-free telephone number and community bulletin board, and weekly teleconferences to review project status.

Having set the stage with some general background information from two other agencies, one DOE NEPA process in particular illustrates the message that early integration of environmental analysis and project design can lead to timely NEPA process completion and can facilitate project approval and implementation. In September 1988, an EIS was begun to analyze the impacts of siting and constructing a new production reactor for the production of tritium, an essential component for nuclear weapons. By April 1991, 31 months after beginning the EIS, a draft EIS was published for public review and comment. Seven months after publication of the draft, public comments were addressed and a final EIS was approved for publication, though world events and related DOE program decisions led to a situation where the final EIS was never published.

Two and a half years for publication of a draft EIS is probably not close to a record-breaker, but in the case of this particular document, it could be considered fairly impressive. This EIS included the analysis of 3 potential sites and 3 reactor technologies (light water, heavy water, and a new technology, modular gas-high temperature), which in combination yielded 9 alternatives, plus the no action alternative. Part of the reason for efficient completion of the draft EIS was the use of a large contractor staff as well as a large cadre of Federal employees, but even with virtually limitless resources, progress could not have been achieved without careful attention to project management and rigorous procedures for the preparation and review of the EIS as it developed. In particular, the integration of reactor design engineers, site operations staff, and environmental resource staff was a major key to success. The ability of these specialists to share information back and forth led to a more efficient process for analyzing impacts as well as the ability to note potential environmental concerns that might be addressed in reactor design. A final step in this particular NEPA process was to review and publish the lessons learned during the particular process (Stull et al, 1992), which proved valuable as a means of communicating what worked and what didn't work for the benefit of subsequent NEPA activities within DOE.

There were a number of recommendations from this document that would be beneficial to virtually any NEPA process, particularly some of the project management aspects, the comment response procedures, and the quality assurance and quality control processes. However, to summarize the biggest key to success, it was that the NEPA process was faithfully followed, including a proactive public outreach and public involvement approach. The production of nuclear weapons is a highly controversial subject (and, in the opinion of the author, good training for involvement in issues related to water in the western U.S.). Despite the controversy and emotions involved on the part of the public, however, this particular process showed that no matter how unpopular a proposed action, opponents feel that they were fairly treated if they are given full opportunity to voice their concerns.

In summary, evidence suggests that better integration of the NEPA process into program management can serve to reduce the time and costs required for successful NEPA compliance. Further, there is evidence to suggest that over the past 30 years, NEPA might have been unfairly blamed for project delays in a number of cases, though it is certain that there are cases when NEPA compliance has been a delaying culprit. There are many examples of attempts to shortcut the NEPA process, leading to costly and time consuming litigation. However, it can be argued that if the NEPA process as laid out in the CEQ regulations implementing NEPA is followed, even allowing sufficient time to do the right analyses and public involvement activities, litigation or delays can be successfully avoided, and better information on both project design and environmental consequences can be made available to the decisionmaker.

CONCLUSION

The sting of the flu shot, though sometimes sharp, is brief and prevents needless pain and suffering later. Environmental compliance is no different. This brief review of experiences at Reclamation and at other agencies in compliance with three major environmental statutes reveals that while the Endangered Species Act, the Clean Water Act, and the National Environmental Policy Act are routinely considered to be obstacles to timely and cost effective project implementation or management, that doesn't have to be the case. They are necessary steps that when taken proactively can prevent future delays or crisis.

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IRRESISTABLE FORCE MEETS AN IMMOVABLE OBJECT: ENDANGERED SPECIES, WATER RIGHTS AND WATER SUPPLY CHALLENGES IN COMPLETION OF THE CENTRAL UTAH PROJECT

Ralph G. Swanson[1]

ABSTRACT

The Endangered Species Act (ESA) is frequently cited as the most powerful environmental law in the United States, if not the world. After 40+ years of planning and construction, the Central Utah Project (CUP) now finds itself squarely in conflict with the ESA in the form of the June sucker *(Chasmistes liorus),* an endangered fish that occurs naturally only in Utah Lake (State of Utah, USA) and spawns only in the Provo River. Both waters are lynchpins for completion of the CUP. Water supplies for the CUP have been committed since the mid-1960's, long before the ESA or the June sucker were prominent, yet recent restrictions imposed under the ESA require that completion of the CUP will be contingent upon making "sufficient progress" towards recovery of the June sucker. Using the provisions of Central Utah Project Completion Act (P.L. 102-575) and Utah water law, the Department of the Interior has secured water from over-appropriated sources to meet one of the most critical needs of the June sucker. New opportunities to make temporary use of Federal project water, implementation of water efficiency projects that benefit water users willing to forego CUP project water, and open market purchases of water rights from willing sellers have succeeded in avoiding the seemingly irresolvable controversies that have plagued Federal water projects elsewhere. Water, on both a temporary and permanent basis, has been secured to meet the needs of the endangered fish while still meeting water project objectives. Costs for water have exceeded $13.6 million ($US) to date. Other elements of progressive thinking and planning are described that are designed to avoid conflicts between the Central Utah Project and the conservation of this endangered species.

INTRODUCTION

The Endangered Species Act of 1973 (ESA) has been described by the Supreme Court as "the most comprehensive legislation for the preservation of endangered species ever enacted by any nation."[2] The ESA's mandates are not merely procedural (ie, requiring completion of a process, such as an environmental analysis, before an action may proceed). Rather, its force and effect arise from its substantive requirements. Federal agencies (and individuals) are affirmatively prohibited from taking actions contrary to the provisions of the act. With respect

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[2] Tennessee Valley Authority v. Hill, 437 U.S. 180 (1978).

to Federal water resources development, the salient proscriptions are found in Section 7 of the ESA: Federal agencies may not take any action which, in the opinion of the Secretary (Interior or Commerce), is likely to jeopardize the continued existence of an endangered (or threatened) species, or adversely modify any designated Critical Habitat.[3] Excellent analyses of the ESA, including definitions of key terms such as "Federal action", "jeopardy" and "Critical Habitat" are in Bean and Rowland (1997), and Rholf (1989), but need not detain us here.

The Central Utah Project (CUP) is the largest participating project in the Colorado River Storage Project and the largest water resources development project in Utah. The CUP consists of a complex system of dams, reservoirs, trans-basin diversion pipelines and water exchanges designed to make use of a portion of Utah's allocated waters under the 1922 Colorado River Compact. The CUP was first authorized for construction in 1956 under the Colorado River Storage Project Act and the Bureau of Reclamation completed its first CUP Definite Plan Report in 1964. The CUP was ably summarized at the 2001 USCID by Murray and Johnston (2001).

Key to operations of the Bonneville Unit[4] of the CUP is Utah Lake, a natural lake first dammed for irrigation purposes over a century ago. Utah Lake is the central exchange facility for the CUP making possible storage and diversion of municipal and industrial water from tributaries to Utah Lake. The lake receives transbasin water deliveries from northeast Utah river basins and, in exchange, gives up its Provo River tributary inflows for diversion to urbanized Salt Lake City and environs.[5]

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[3] The authority of the Secretaries to develop such opinions and make findings has been delegated to the U.S. Fish and Wildlife Service (Department of the Interior) and National Marine Fisheries Service (aka NOAA fisheries) (Department of Commerce).

[4] The Bonneville Unit is the largest unit of the CUP developing, primarily, municipal and industrial water. Other CUP units provide irrigation water supplies. See Murray and Johnston (2001).

[5] A second federal water project, the Provo River Project (PRP), also impounds, develops and diverts the Provo River, as well as imported water, otherwise bound for Utah Lake. The PRP, though completed in the 1940's, is not exempt from ESA requirements. In a 1994 Biological Opinion evaluating ongoing operations of the PRP, FWS concluded that the PRP is likely to jeopardize the June sucker and adversely modify its Critical Habitat. The FWS required the Bureau of Reclamation to, among other actions, acquire water in the Provo River to ensure adult June sucker spawning and maintain high quality aquatic conditions for egg and larval survival. This Biological Opinion was the first restriction on Federal water project operations on the Provo River and presaged requirements eventually placed on the CUP (USFWS, 1994).

The June sucker (*Chasmistes liorus*), a fish endemic to Utah Lake, was listed as an endangered species under the ESA in 1986 (51 FR 10857) primarily due to degradation of its natural habitats in Utah Lake and the Provo River by water diversions, competition and predation by introduced non-native fish, and degraded water quality (USFWS, 1997). Critical Habitat for the fish was also designated as the lower 4.9 miles (7.8 km) of the Provo River from Utah Lake upstream to the Tanner Race Diversion (Columbia Lane, City of Provo). The June sucker occurs naturally only in Utah Lake and spawns only within its Critical Habitat in the lower reaches of the Provo River.[6]

As construction elements of the Bonneville Unit continued, conflicts between the project and conservation objectives for the June sucker increased. Among the many factors impeding June sucker recovery, the lack of springtime flows in the Provo River to support June sucker spawning became immediately acute. In 1998, the USFWS issued its Biological Opinion on completion of the Diamond Fork System, Bonneville Unit, CUP which evaluated the depletion of additional water from the June sucker Critical Habitat (USFWS, 1998). Restrictions and commitments placed on the Federal action agencies with respect to the Diamond Fork System were similar to those applied to the Provo River Project. See footnote 5. Specifically, the Federal agencies were to continue acquiring additional water in the Provo River basin to support June sucker spawning, and they were to develop a Recovery Implementation Program for the June sucker (see below). Most significantly, USFWS ruled that future development of the Bonneville Unit, CUP would be contingent upon the Recovery Implementation Program making "sufficient progress" toward recovery goals for the June sucker.

These requirements energized the Federal action agencies and their partners to address recovery actions. Priority consideration focused on securing sufficient water in the Provo River, and managing the spring runoff, to support and ensure successful spawning of the June sucker within its Critical Habitat.

<u>Federal Project Water Supplies</u>

The availability of unused CUP water in Jordanelle Reservoir, the main CUP storage facility on the Provo River, offered the first opportunity to address the growing crisis represented by the lack of water in the Provo River to sustain June sucker spawning. Construction of Jordanelle Reservoir was completed in 1993 and filled in 1996. Delivery of CUP water from Jordanelle Reservoir to customers was limited to much less than a full supply during these years pending

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[6] Naturalized populations of the June sucker have been established in other waters outside Utah Lake, including Red Butte Reservoir (Salt Lake County, UT) where the population also spawns. These refuge populations have been established and are protected and maintained as recovery actions in accordance with the approved June Sucker Recovery Plan as means of avoiding extinction of the species.

the construction of other Bonneville Unit features that would allow for exchange of the full CUP water supply in Utah Lake.

The Central Utah Project Completion Act of 1992 includes important new authorities and flexibilities to use Federal project water supplies already under contract, but not yet in full use by customers. The Bureau of Reclamation, Department of the Interior CUPCA Office, and Central Utah Water Conservancy District (CUWCD), the local sponsor of the CUP, made use of these new authorities to secure a portion of this unused CUP water to meet the June sucker spawning flow requirements imposed by the USFWS under the ESA. Facilitating this process was the authorization in CUPCA for the Department to reduce the annual contractual repayment obligation of the CUWCD for the water secured. This opportunity to offer repayment savings, in exchange for temporary use of water, provided the incentive for cooperation to address this seemingly intractable problem.

Table 1 displays the amount of unused Federal project (CUP) water secured to assist June sucker spawning in the lower Provo River. Since 2000, the parties have not had to rely on unused Federal project water. Instead, other CUPCA authorities have been used, as described below.

Table 1. CUP Water Secured for June Sucker Spawning, 1994-2000 (AF)

1994	1995	1996	1997	1998	1999	2000
1,600	5,000	5,000	5,000	6,800	5,000	5,000

Water Management Improvement Program - CUPCA Section 207

The Water Management Improvement Program (WMIP), established by Section 207 of the CUPCA, is a comprehensive program to implement water conservation and improve water management within the CUWCD service area. The WMIP is operated by the CUWCD using Federal appropriations combined with local funding. Water conservation measures are broadly defined as actions to improve the efficiency of storage, conveyance, distribution, or use of water.[7] A plan describing program goals, the application process, description of previously implemented projects, and an implementation schedule for the coming five years has been prepared by the CUWCD (2004).

While the WMIP is voluntary, it also offers powerful financial incentives.[8] First, water saved by conservation measures may be retained by the applicant (the

[7] Dams, reservoirs and water wells are not eligible conservation measures.
[8] Improved water management raises a number of important concerns within the water community: 1) under Utah law conserved water is not necessarily the property of the operator who saves it, but rather goes to the next appropriator; 2)

individual water user applying for WMIP funds); alternatively, saved water may be relinquished by the applicant for instream flow purposes. As with unused Federal project water, the Secretary will reduce the annual repayment obligation of the CUWCD in an amount equal to the project rate (including operation and maintenance costs) for the CUP water dedicated to instream flows. This credit, in turn, flows back to the applicant. The WMIP program is structured to allow CUP and non-CUP water to be used for instream flow purposes on a temporary or permanent basis. Moreover, the program is operated in a manner that favors projects that return saved water.

With these new authorities, the Federal and non-federal partners in the CUP have successfully secured significant water in the Provo River basin to assist the spawning of June sucker. Table 2 displays the water secured since 2000 under the WMIP to assist June sucker spawning in the lower Provo River.

Table 2. Water Acquired to assist June sucker spawning

Year	Acre-Feet
2000	6,300
2001	9,672
2002	9,672
2003	10,672
2004	12,172
2005	7,772
2006	7,002
2007	6,702
2008	5,702
2009	5,702
2010	5,702

Source: Central Utah Project Completion Act Office
Table 2 includes temporary and permanent water. Permanent water will be available beyond 2010. Additional acquisitions are expected to alter the table.

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water efficiencies that eliminate seepage/evaporative losses or the need for "carrier water" in open canals, create water that may be available for appropriation by others; 3) diverting/selling less water reduces revenues, thus potentially impacting current operations, loan/bond repayment ability and financial integrity of water agencies; 4) "take or pay" contracts bind petitioners to pay for water whether they use it or not. Taken together, these forces may actually encourage consumption of water. Discussion of these issues is beyond the scope of this paper, but offers fruitful topics for analysis in other forums.

Open Market Purchase of Water – CUPCA Section 302(a)

Authority and funding to acquire available water (water rights) by purchase or exchange from willing sellers in the Provo River basin is provided by Section 302(a) of CUPCA. This water acquisition program is also operated by the CUWCD with Federal funding.

Fifteen million dollars ($15,000,000 $US) is authorized to acquire up to 25,000 acre-feet. This objective is linked to a separate goal of maintaining a year-round minimum flow in the lower Provo River of 75 cfs. Thus, this provision is not strictly for the maintenance of June sucker spawning. However, all parties have agreed that, until the administrative clearances (discussed below) are complete, available water will be managed for springtime releases to benefit June sucker.

In Utah, as elsewhere in the rapidly urbanizing west, water markets are increasingly competitive. Municipalities along the Wasatch Front frequently have standing offers to purchase available water.[9] Nevertheless, notable progress has been made. Acquisitions representing approximately 3,300 acre-feet have been secured to date. It is important to note that most of this water is in the form of privately-held shares in local irrigation or canal companies. Typically, a share represents ownership in the parent company which owns the water right. Under Utah law, an application must be processed through the State Division of Water Rights (State Engineer) before water represented by the shares can be "segregated" as a separate water right to be left in the river. This process is lengthy and requires concurrence of the parent irrigation/canal company. At present, the first application is pending before the State Engineer. Thus, very little of the water acquired using Section 302(a) funding has been available in the river and this water is not included in Table 2 or Figure 1. However, all parties anticipate the state will eventually approve the appropriate applications necessary to make this water available in the Provo River where it can benefit June sucker.

Discussion

Figure 1 provides a summary of water acquired (exclusive of open market purchases) to support June sucker spawning in the lower Provo River projected through 2010. Permanent water will be available beyond 2010, and additional water acquisitions are anticipated.

[9] At this writing, open market prices are $1,200 - $1,400 ($US) per acre-foot.

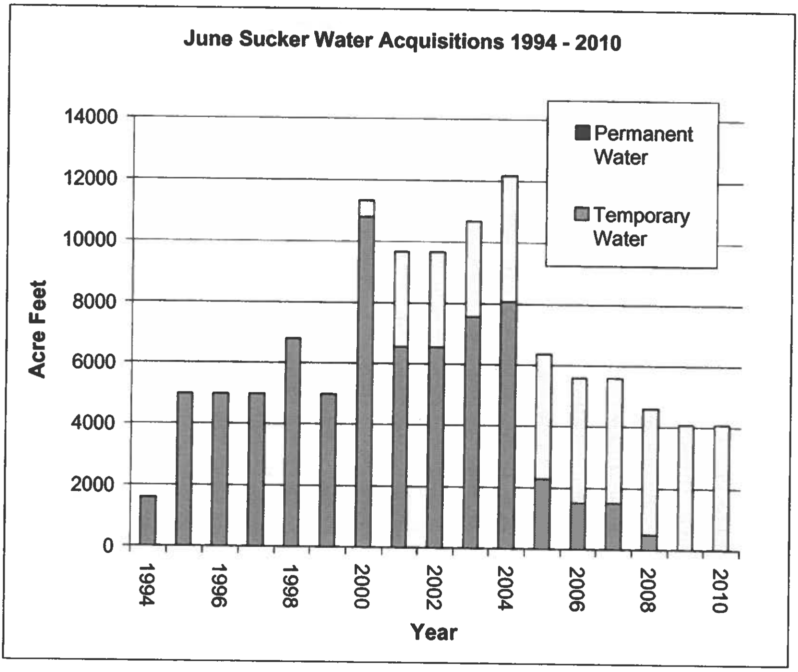

Figure 1. Water Acquired for June Sucker

Despite the prior appropriation of virtually all available water in the Provo River[10] the parties have succeeded in securing water to benefit the endangered June sucker. Moreover, the fish has spawned successfully in its Critical Habitat in the lower Provo River each year since water acquisition efforts first began in 1994.

As indicated in Figure 1, generally increasing amounts of water have been secured through 2004. After 2004, loss of temporary supplies will substantially reduce available water. However, cooperative efforts will continue (in all three program areas discussed in this paper). The parties are actively pursuing a number of promising opportunities for additional water acquisitions.

These accomplishments are not without financial cost. Credits toward a water project repayment obligation represent a loss of revenues otherwise anticipated by the U.S. Treasury. Table 3 displays costs (ie, revenues foregone plus operation and maintenance charges) for water acquisitions for June sucker.

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[10] Water represented by extreme snowmelt or excessive rainfall may be available, but such water is intermittent, at best, and largely infeasible to develop.

Table 3. Water Costs

Year	Amount ($US)
1994	276,738
1995	864,806
1996	864,806
1997	864,806
1998	1,406,267
1999	1,036,565
2000	2,330,522
2001	2,187,326
2002	1,785,610
2003	2,010,237
Total	**$ 13,627,683**

Source: Central Utah Project Completion Act Office, Provo, UT

Water has cost over $13.6 million ($US) to date. Moreover, these costs are anticipated to continue indefinitely at a level of about $2 million ($US) annually. Had recovery actions been initiated sooner, progress might have been achieved at lower cost.

A number of progressive ideas have resulted from agency interactions to avoid and resolve conflict between the endangered June sucker and the CUP. These initiatives have been successful for the CUP, and are offered as models for application to similar controversies.

<u>June Sucker Recovery Implementation Program (JSRIP):</u> Responding to directives in the USFWS Biological Opinions, a coalition of nine Federal, state, and local agencies, plus non-governmental outdoor interest groups, formed the June Sucker Recovery Implementation Program (JSRIP) to address the full range of factors limiting the recovery of the June sucker. The JSRIP is a multi-agency cooperative effort to implement the approved June sucker Recovery Plan by facilitating recovery of the June sucker while accommodating water resource needs for the human population in the Provo River basin (JSRIP, 2002). An interactive visual presentation describing the recovery program is displayed at this conference (Keleher and Shawcroft, 2004).

<u>June Sucker Flow Workgroup:</u> In 1994 the agencies involved in, or affected by, management of flows on the Provo River formed a workgroup under the leadership of the Bureau of Reclamation to evaluate hydrologic conditions in the Provo River basin each spring and make recommendations for river flow management (quantity, timing, delivery pattern, etc.) to benefit the June sucker. Recommendations are provided to the CUWCD which has the responsibility to operate the CUP with respect to project water in the Provo River. In 2002, this workgroup was incorporated into the JSRIP.

June Sucker Recovery Team: At the request of the key parties, the U.S. Fish and Wildlife Service designated a formal Recovery Team for the June sucker in 1998.[11] The Recovery Team has been very active in advising the JSRIP participants on all aspects of program implementation. The Team is independent of the JSRIP, but provides an important "peer review" for JSRIP program actions.

CONCLUSIONS

It is almost always possible to conserve endangered species without significantly harming our short term interests in water and related resources development. There have been few truly irresolvable conflicts under the ESA to date. However, the resource agencies responsible for implementing the ESA (U.S. Fish and Wildlife Service and NOAA Fisheries) cannot succeed alone. They lack resources in both funding and staff capability to evaluate the engineering, hydrology, and operational aspects of a complex water project. This limits their ability to develop feasible solutions in all cases. The ESA authorizes and directs all Federal agencies to utilize their existing authorities to conserve endangered and threatened species (16 USC 1531(c)). Thus, the mandate to conserve listed species is integrated with--arguably coequal with--other agency missions. Ideally, this should result in the avoidance of conflicts by effective interagency consultations with resource agencies. However, this can not happen without the active support and involvement of the water development community. By means of practical and creative--even unconventional--alternative actions that can only be conceived by the wildlife and water agencies working in concert, water project activities can be compatible with the conservation of listed species.

The administrative will exhibited by key parties involved with completion of the Central Utah Project, together with the progressive Congressional authorities crafted within the Central Utah Project Completion Act of 1992, have resulted in a successful cooperative effort to avoid irresolvable conflicts between the project and conservation of an endangered species by securing water once assumed to be unavailable.

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11 A Recovery Team is a panel of species experts from Federal, state or local agencies (and the private sector if appropriate) with the specific mandate to advise the USFWS Regional Director on the recovery of a listed species. Recovery Teams often, but not always, prepare Recovery Plans.

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ACCOMPLISHING THE IMPOSSIBLE: OVERCOMING OBSTACLES OF A COMBINED IRRIGATION PROJECT

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ABSTRACT

During the past five years of record-breaking drought, the impossible was done when the unlikeliest group collaborated in western Uintah County, Utah. Individuals from the Uintah Water Conservancy District, the Ouray Park Irrigation Company, the Uintah River Irrigation Company, and the Ute and Ouray Indian Tribes, represented by the Bureau of Indian Affairs, agreed to implement an irrigation project that would combine seven irrigation canals into a single pressurized delivery system. These individual groups had many obstacles and historical mistrust to overcome before construction even could begin on the West Side Combined Canal Salinity Project (WSCCSP).

The first obstacle was to acquire sufficient funding to design and construct the five divisions of the WSCCSP. Another obstacle faced was coordinating and improving the ecological and environmental issues by increasing instream flows and tightening salinity control in order to be eligible to receive the needed Federal funding for the project. There was also the sensitive subject, especially in times of drought, of juggling the water rights of the project participants. The project areas' water rights include Native American water rights and non-Tribal water rights. Some participants have storage rights while others have only direct flow rights. Probably the most difficult obstacle was socio-economic. The historical mistrust between the entities needed to be resolved and the project participants have cooperated to share resources rather than compete for a less than adequate water supply.

These obstacles, having been overcome, have resulted in very apparent project benefits. With three of the five project divisions complete, water has been conserved, water deliveries have been maximized, crops yields have increased, and the usable water supply has been increased through better efficiency and management.

INTRODUCTION

The West Side Combined Canal Salinity Project (WSCCSP) is a large irrigation project located near Gusher in Uintah County, Utah. It consists of replacing

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seven irrigation canals with one pressurized irrigation delivery system. The seven canals are owned and operated by two irrigation companies and the Ute and Ouray Indian Tribes. Before conception of the WSCCSP, each canal was operated separately by its respective owner. As the water source for all of the canals is the Uinta River, the irrigation companies and Tribes often competed for water. In order for the WSCCSP to be successful, the irrigation companies and Tribes would have to work together to overcome many obstacles. The four major obstacles included obtaining project funding, satisfying environmental and ecological requirements, juggling water rights, and easing historical mistrust.

PRE-PROJECT CONDITIONS

Project Participants

In April 1998, the Uintah River Irrigation Company (URIC) applied for funding from the Colorado River Salinity Control Program to replace a portion of the Moffat Canal with a pressurized pipeline. URIC sought assistance from the Uintah Water Conservancy District (UWCD) to formulate a project plan. During the plan formulation process, the Ouray Park Irrigation Company (OPIC) and the Ute and Ouray Indian Tribes, represented by the Bureau of Indian Affairs (BIA), were invited to the planning meetings because of the proximity of their canals and irrigated lands to the Moffat Canal. The Moffat and Ouray Park Canals parallel each other for the entire length of Moffat Canal. The purpose of the planning meetings was to study the possibility of combining all the canals into a single distribution system. Each participating entity chose a representative to serve on a project steering committee.

Project Need

As all of the project participants divert water out of the Uintah River, water rights play a key role in determining who gets water when. Many of the rights are for direct flow. Therefore, in dryer years those with a lower priority, i.e. URIC, may only receive water during high flow. Since the canals are not lined, much of the water is lost to seepage. Delivering water through pipe would save water lost to seepage, and therefore, would increase the water supply of those with lower priority rights.

Also, many of the landowners have chosen to flood irrigate rather than pump water from the canals into sprinklers. A pipeline distribution system that is pressurized by gravity would allow landowners to convert to sprinklers without having to pay pumping costs. Due to the variability of the volume and timing of water availability, landowners expect that sprinkler irrigation will increase overall irrigation efficiency.

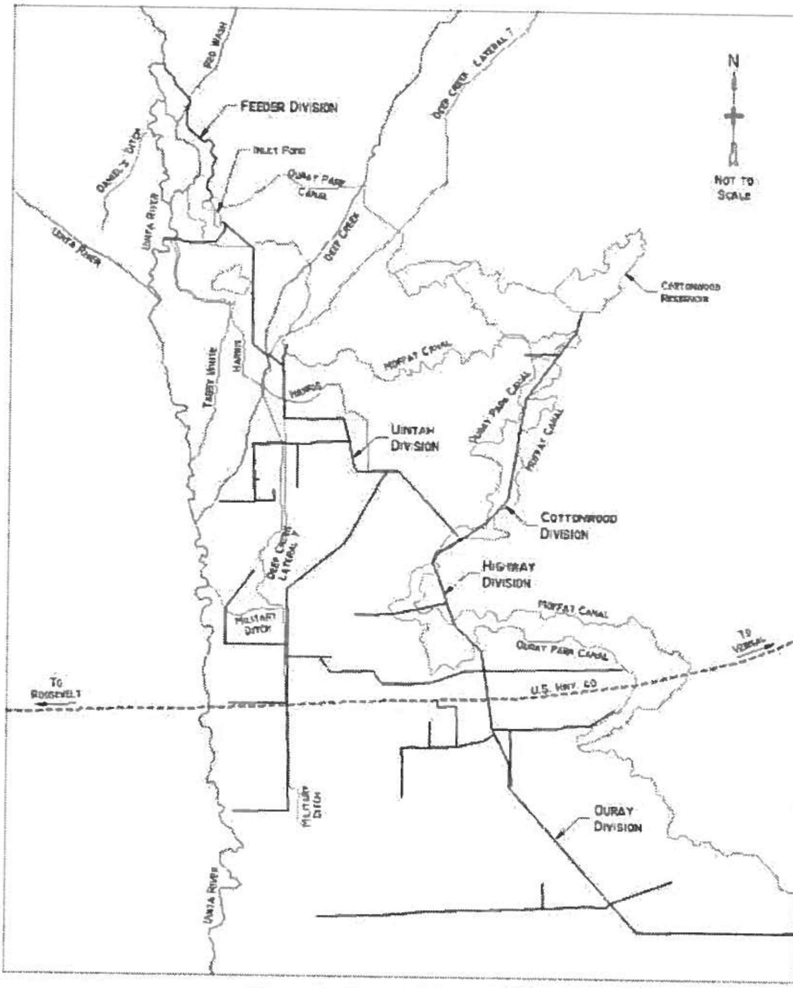

Figure 1. Project Location Map

Design Concept

Service area: The seven canals to be replaced and the acreage served by each are summarized in Table 1.

Table 1. Participating Canals

Canal	Governing Organization	Length of Canal to be Replaced (miles)	Area Served (acres)
Ouray Park Canal	OPIC	15.3	9,553
Moffat Canal	URIC	16.4	2,044
Daniels Ditch	BIA	1.0	151
Tabby White Canal	BIA	2.5	196
Harris Ditch	BIA	5.9	425
Military Ditch	BIA	2.6	852
Deep Creek – Lateral 7	BIA	2.7	763
Total		46.4	13,984

Project Facilities: To facilitate funding, design, and construction, the WSCCSP was separated into five divisions, namely Feeder, Uintah, Highway, Cottonwood, and Ouray, as shown in Figure 1.

- The Feeder Division consists of a combined diversion structure, a measurement flume, and approximately 1.5 miles of lined canal.
- The main trunk line of the Uintah Division consists of 23,900 feet of steel and PVC pipe ranging from 42-inch to 24-inch. The laterals consist of 47,000 feet of PVC pipe ranging from 21-inch to 4-inch.
- The Highway Division consists of 12,250 feet of 48-inch diameter HDPE pipe and 62,200 feet of PVC pipe ranging from 24-inch to 2-inch.
- The Cottonwood Division consists of 12,600 feet of 48-inch HDPE pipe and 2,700 feet of 12-inch PVC pipe.
- The Ouray Division consists of 16,000 feet of 48-inch HDPE pipe and 4,375 feet of 18- and 21-inch PVC pipe.

In total, the project includes over 12 miles of main trunk line and 22 miles of laterals.

DESCRIPTION OF MAJOR OBSTACLES

Funding

The first major obstacle that the project participants had to overcome was acquiring enough funding to design and construct the WSCCSP. When the WSCCSP was reformulated to include all of the project participants, UWCD applied for funding for the WSCCSP from two main sources, the Colorado River Basin Salinity Control Program and the Water Conservation Credit Program of the Central Utah Water Conservancy District (CUWCD).

The Colorado River Basin Salinity Control Program managed by USBR provides funding to projects that reduce the salt loading in the Colorado River by implementing irrigation improvements. The Water Conservation Credit Program managed by CUWCD provides funding to projects that conserve water by implementing more efficient delivery and application of irrigation water.

It was planned that combined money from the two sources would cover the cost of the entire project. However, only the application for money from the Salinity Control Program was successful. The steering committee was faced with the decision to either put the project on hold until enough funding was secured for the entire project or to try to begin design and construction on two of the five project divisions.

NEPA/Cultural Resources

As a result of receiving Federal funding from the Salinity Program, the WSCCSP participants faced the second major obstacle, NEPA compliance. Fortunately, due to a previous Environmental Impact Statement on the Uintah Basin Salinity Project by the Natural Resources Conservation Service (NRCS), a complete Environmental Assessment was not necessary. Instead, a Site Specific Environmental Evaluation Checklist would fulfill the NEPA requirement. The checklist, however, contained two hurdles, biological mitigation and cultural resources work.

Biological mitigation: Though abandoning canals has the benefit of reducing water loss and salinity in the Colorado River, a major disadvantage is the loss of wetlands and riparian habitat. NEPA requires mitigation for all loss of habitat. UWCD hired a consultant to assess the biological effects of the WSCCSP and to prepare a mitigation plan. In order for the mitigation plan to be implemented, each of the project participants would have to contribute land or water for habitat.

Cultural resources: The NEPA checklist was signed with the understanding that cultural resource surveys would be completed as the project was implemented. Since the surveys are based on the pipeline alignment and not all of the divisions were designed concurrently, many surveys were necessary. Compounding the issue, different archeologists were employed for each division's survey. Much of the Uintah Division was located on Tribal land. The Tribe requires surveyors to apply for a special permit before investigations can begin. A delay in getting the necessary permit caused a delay in completing the cultural resources inventory in time for construction to begin. Also, as archeological sites were found, some alignment changes were necessary to avoid those sites. This added time and cost to the process as the new alignment also needed to be surveyed.

Water Rights

Under pre-project conditions each of the seven canals had a separate diversion out of the Uintah River. When the project participants diverted water out of the river depended on their water rights. As the Feeder Division of the project included replacing the seven separate diversions with one combined diversion dam, it was imperative to understand the who, how much, and when of the water rights. Even though the project participants were agreeing to combine their water physically, they insisted that the water rights would remain intact and unchanged. It was not easy to juggle the water rights as they differed in priority date, some allowed for storage while others were only for direct flow, and some were for Tribal water. Once all of the pertinent rights were located, applications were filed to change the point of diversion for each to the location of the combined diversion dam.

Mistrust of Project Participants

Throughout history, neighbors have fought over limited water supply. The participants of the WSCCSP are no different. With separate diversions and canals, there was less chance of conflict since each entity diverted water according to their respective rights. With the combined diversion and pipeline project, however, water would be commingled. The project participants would be forced to work together to ensure water was distributed appropriately.

HOW EACH OBSTACLE WAS OVERCOME

Funding

As a result of the original application to the Salinity Program, UWCD entered into a contract with the U.S. Bureau of Reclamation (USBR) for $6.85 million. As this amount did not cover the cost of the entire project (roughly $15 million), UWCD decided to proceed with the Feeder and Uintah Divisions. USBR agreed to provide UWCD with about half of the $6.85 million, which could be justified by the actual salt reduction realized by the first two divisions.

In the fall of 2002, UWCD was ready to proceed with the Highway Division. After several months of negotiations, an agreement was made between UWCD, USBR, and NRCS. NRCS would fund, design, and construct the Highway laterals. UWCD would proceed with design and construction of the Highway main pipeline, which USBR would fund with the remaining half of the $6.85 million contract. The agreement and resulting actions would allow for the delivery of water to the lands served by the Highway laterals. Water delivery to those lands had been on the NRCS priority list for several years.

Now, in 2004, UWCD is requesting additional funding from the Salinity Program to complete the final two divisions of the WSCCSP. With completion of the

Cottonwood and Ouray Divisions, the remaining salinity control benefits anticipated for the project can be accomplished.

NEPA/Cultural Resources

Biological mitigation: As part of the NEPA compliance process, a mitigation plan for loss of wetlands and riparian habitat was prepared and concurred with by the USBR and the U.S. Fish and Wildlife Service (USFWS). The mitigation plan was formulated to provide increased instream flows. By combining the seven diversions, 15 cfs of water that was diverted upstream remains in the Uintah River for an additional 4.5 miles. Also, flows in the nearby Red Wash that were diverted by URIC now have no way into the pipeline. These flows, which range between 4 and 7 cfs, flow into the Uintah River below the combined diversion.

Abandonment of the canals could potentially result in loss of habitat along their banks. In order to sustain some of the best habitat of trees and shrubs, sections of the two major canals would be blocked off to catch natural inflow from adjacent drainages. Also, to mitigate the potential loss of habitat, some local ponds that were used for irrigation water storage were designated to become wildlife habitat. Project participants were asked to share in the responsibility of providing water to keep the mitigation ponds full. Some participants, however, felt that requiring each participant to supply a certain amount of water was asking too much. The steering committee agreed that the participants who would not supply water for mitigation could provide land for wildlife habitat.

Cultural resources: The first cultural resources inventory completed was for the Feeder Division, which involved a new diversion structure at the Uintah River and lining a portion of the Ouray Park Canal. Since the project area was previously disturbed, the cultural resources survey was fairly straightforward resulting in few archeological sites.

Cultural resources work became a true obstacle when work began on the Uintah Division. When the decision to proceed with the Uintah Division was made, there was just four short months to complete design and award a construction contract. Cultural resources work began immediately, but it was not soon enough. Since a large portion of the Uintah Division was located on Tribal land, the archeologist needed a special permit to conduct the necessary surveys and site inventories. It took several weeks for the Tribe to award the permit. The permit was awarded with the condition that a Tribal archeologist be present for all surveys and construction done on Tribal land. As the archeologist conducted the survey, several sites were found that resulted in a change of pipeline alignment. The cultural resources work on the Uintah Division was an iterative process as new alignments were designed and surveyed. By the time the permit was given, the surveys completed, and the inventory report was written, the construction contract had been awarded, but concurrence from the State Historical Preservation Office

(SHPO) was still pending. Due to the approach of winter, it was imperative that the contractor begin work. Special permission was requested from SHPO to begin construction on previously disturbed ground. Fortunately, the request was granted, with the stipulation that an archeologist be present.

Since NRCS took the lead on the design and construction of the Highway Division laterals, it was negotiated that the NRCS archeologist would complete the cultural resources survey for the entire Highway Division. SHPO concurrence was received without any problems.

Water Rights

Memorandum of Understanding: A Memorandum of Understanding (MOU) among the Uintah River Irrigation Company, the Ouray Park Irrigation Company, the Bureau of Indian Affairs, and the Uintah Water Conservancy District was signed on September 28, 2000. The MOU is intended to be the framework to allow the WSCCSP to move forward through planning, design, construction, and operation for the benefit of water users in western Uintah County. One of the main issues resolved in the MOU is the management of the various water rights involved in the project. The MOU explicitly states that the implementation of the WSCCSP will not change any ownership, priority date, or place of use for the water rights. Only the point of diversion and means of conveyance shall change.

Storage agreement: Because of the mitigation plan, however, pre-project water use did have to change. As stated earlier, water from Red Wash that was used by URIC would instead be used for instream flows. Also, URIC would cease use of their storage ponds. These changes would effect the timing of when URIC would have water available to them. Therefore, URIC entered into a storage agreement on May 16, 2000 with OPIC to define the use of Cottonwood Reservoir under project conditions. The storage agreement would allow URIC to use 600 acre-feet of Cottonwood Reservoir's 6,000 acre-foot capacity, and URIC would reimburse OPIC with its direct flow rights.

Mistrust of Project Participants

Project participants were hesitant to trust each other before the conception of the WSCCSP, let alone when the water would be commingled. Therefore, members of the steering committee have entered into several agreements that make the WSCCSP possible. Each agreement went through the draft and review process to ensure each participant's interests were protected.

Memorandum of Understanding: As stated above, the MOU was vital in outlining how the participants would work together to not only implement the project, but also operate and maintain the completed system. The MOU also defined water measurement, which would ensure water rights were respected.

Storage agreement: The storage agreement is evidence that the project participants were able to compromise. By sharing facilities, the irrigation companies were able to simultaneously optimize their water supplies, honor mitigation agreements, and allow the project to move forward.

Carriage agreements: As a supplement to the MOU, a Carriage Agreement (CA) between the Uintah River Irrigation Company and the Bureau of Indian Affairs (BIA) has been developed to define the use of the Uintah Division to carry water for both entities.

O&M Manual: An Operation and Maintenance Manual was developed for the interim use of the WSCCSP completed divisions. The BIA and URIC operate the Uintah and Highway Divisions, respectively. Training was provided to BIA and URIC personnel who operate and maintain the system. The Operation and Maintenance Manual will be updated and refined over time as the remainder of the system is installed.

SCADA system: A remote telemetry system, known as Supervisory Control and Data Acquisition (SCADA), is to be installed throughout the combined system. As each lateral has been equipped with a metering device, project participants will be able to monitor that water use is representative of the water rights. USBR has already partially installed the telemetry system on the Uintah Division. The telemetry system on the Highway Division should be operational by the 2005 irrigation season. This accessibility to accurate measurement of inflow and outflow is a key feature in the success of the WSCCSP.

POST-PROJECT CONDITIONS

Current Project Status

As of the summer of 2004, three of the five project divisions are complete. The Feeder Division including the combined diversion and the canal lining was completed in August 2001. The Uintah Division was designed and constructed between May 2001 and June 2003. In April 2004, construction of the Highway Division was completed.

UWCD is presently negotiating with USBR for additional funding from the Salinity Program to design and construct the Cottonwood and Ouray Divisions.

The success of the WSCCSP is shown in Figure 2, as lands once served by the Moffat Canal and Tribal canals are receiving water from the pipeline. Had the project not been implemented, these lands would not have received enough water to irrigate in these past few dry years.

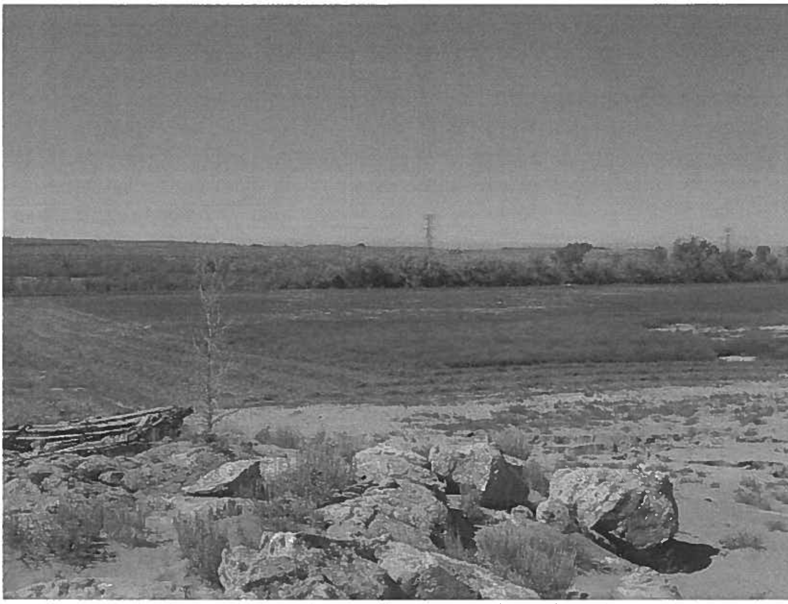

Figure 2. Land that received water through project.

CONCLUSION

By working together the project participants were able to overcome several obstacles of implementing a combined irrigation project. By recognizing the obstacles early, the participants were able to find solutions before the obstacles became impediments. The steering committee was patient as applications for funding were approved, rejected, and modified. Each participant compromised and contributed something to the mitigation plan for environmental compliance. The water rights of each participant were respected. Most importantly, the historical mistrust was managed by developing agreements that outlined each participant's responsibility toward construction and project operation. In the end all participants realized that they needed each other and the project in order to maximize their individual water supplies.

The future operation of the project depends on building on the newfound relationships of trust and cooperation. The system has been designed and is operated based on new technology and different measurement techniques. Reverting to old ways of doing business is no longer possible if the project is to maximize improved operation and water availability benefits. There will still be adjustments and growing pains in fully implementing the project.

THE MANAGEMENT OF AUSTRALIA'S WATER RESOURCES AND ITS WATER REFORM AGENDA

Dianne Deane[1]

ABSTRACT

This paper provides an overview of water resource management in Australia, in the context of Australia as one of the driest continents on earth. It outlines the political and institutional management structures for water resources. It also outlines the successes of the last decade of water reform and our vision for the future through the recent Intergovernmental Agreement on a National Water Initiative. The National Water Initiative has at its heart, the objectives of a national approach to secure water entitlements, open water trading markets and the assignment of risks in sharing water resources between the environment and consumptive uses. Sustainable use of our water and providing security for users to allow for continued investment in water use efficiency, are paramount. Our major food producing area, the Murray Darling Basin has unique management structures in place to ensure equitable sharing of the water resource between the states and territories. The Basin will also benefit from a new intergovernmental agreement that will provide Aus$500 million in funding over five years to address the overallocation of its water resources. A major environmental water program to achieve specific environmental outcomes for six nationally significant environmental icon sites in the Basin has also been agreed. These agreements and the management arrangements for sharing the Basin's water resources for both productive and environmental purposes are also outlined.

THE NATURE OF AUSTRALIA'S WATER RESOURCES

"I love a sunburnt country, a land of sweeping plains
Of rugged mountain ranges, of drought and flooding rains."
These lines are from one of the first poems taught to young Australian schoolchildren. They are taken from Dorothea McKellar's 1908 poem, "*My Country,'* written when she was a 19 year old university student in Sydney. The poem goes on to describe the difficulties of surviving this harsh land's changing nature and illustrates that we have long understood its constraints.

We lay claim to being the driest inhabited continent on earth. While our average annual rainfall is 18 inches (457mm) or 570,733 acre feet (3,520,000 gigalitres), these figures mean little given the great variation in the geographic distribution and seasonal timing of our rainfall. We have the lowest amount of water in rivers and the smallest area of permanent wetland. We have the lowest percentage of

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rainfall as run off - our 2002 *National Land and Water Resources Audit* tells us that only 12% of our rainfall runs off to collect in rivers, half of which are northern tropical rivers where there is sparse development and little scope for diversion and the water flows into the sea.

Our major river catchment system, the Murray Darling Basin, where most of our agriculture is centred, receives only 6.1% of the runoff. Storage of water is therefore critical. Australia stores more water per head of population than any other country – some 4 million litres per person. Our Murray Darling Basin is one of the most regulated water systems in the world boasting 84 storages with capacities of 16.2 acre feet (10,000 ML) capacity and over 3500 weirs. Together these are capable of storing 3 times the annual flow of the Murray River. Without these storages and their associated reticulation systems much of Australia's rural and regional development and agriculture as we know it today would not exist.

We have officially been in drought for the last seven years, compounding the work of management of economic and population growth with environmental protection with a limited water resource. Five of our seven capital cities have imposed harsh restrictions on water use and two of these cities are considering making such restrictions, permanent.

There are significant environmental issues. According to our National Land and Water Resources Audit, average natural flows from the Murray River to the sea have been reduced by 75%. Dredging is required to keep the river mouth open. Of Australia's 325 defined surface water management areas, some 84 (26%) are close to, or overused when compared with sustainable flow regimes. Some 161 (30%) of our 538 groundwater management units are close to or overused. But we are on a firm path to addressing these issues.

Most available dam sites have already been used and in the medium term, for more developed regions, more dams do not seem to provide the answer for the provision of more water. And despite constant calls from the public to build north-south pipelines to 'water-proof' Australia, the infrastructure and energy costs are prohibitive even where these are technically feasible. A recent report prepared for the Government of South Australia, our driest state, estimated that consumers would have to pay between 600-900% more for water from such grand schemes.

In summary, our water resources are scarce, variable and well-harnessed. There is further cause for concern over the reliability and distribution of rainfall from climate change. This is a hard pill to swallow for a nation that has a high per capita water use (Australian ***per head residential*** use is roughly half that of the United States.)

However, to our credit we make good use of our agricultural water and feed four times our population. Food and fibre are amongst our key exports and irrigation is a major contributor to our agricultural production and our exports. As an example, around 85% of the rice that our nation produces is exported and up to 40 million people in 70 different countries eat Australian rice every day. Our rice growers have achieved a 60 percent improvement in water use efficiency in the last ten years and Australian growers produce almost 50 percent more rice per hectare compared to the world average (9 tonnes per hectare compared to 5 tonne average across the rest of the world). Australia's irrigation industries now use about three quarters of all water used. The sectors using the most water are livestock (particularly dairy on irrigated pasture), cotton, rice and sugar. The genesis of our irrigation industry can be traced to the American Chaffey brothers, who commenced irrigation in the Renmark and Mildura areas on the River Murray in 1887.

In 1996/97 half of the profit from agriculture came from irrigated production systems, worth over Aus$9 billion - and from less than 0.5% of the land area (2.6million hectares).

New research shows that irrigation industries add more than Aus$12 billion annually to the Australian economy and provide 188,000 jobs. This research conducted by the Centre of International Economics under the Australian Government's, National Program for Sustainable Irrigation, also shows that without irrigation, Australia's exports would fall by almost Aus$7.5 billion, while imports would rise by Aus$4 billion annually.

Irrigation industries are an integral part of many regional economies and the national economy. However, irrigation infrastructure efficiency in some areas could be improved and attempts to ensure that water goes to higher value uses can be accelerated. Our irrigation development and use of water resources in the past has resulted in stream and soil salinisation and changes in habitat and in ecosystem function.

Sustainability of our water resources is essential, not only for our unique environment but also for our rural and urban communities and for our economy. A strong national focus on the sustainability of our water resources became a national objective over a decade ago and the need to maintain the momentum has been reinforced. Continued emphasis on integrated water management, cross-border cooperation, improving irrigation practices and water use efficiency in our cities and greater efforts in re-use and recycling are needed to ensure continued productivity and environmental sustainability.

RESPONSIBILITY FOR WATER RESOURCE MANAGEMENT

Historically, land and water management has been a political issue – Australia is a Federation of provincial governments (6 States and 2 Territories) and under our Constitution, management of natural resources rests with these governments. Water sharing was a major issue for our Federation before it had begun, with much argument as to whether water would be the responsibility of the new national government-to-be or remain with the states. With Federation in 1901, water resource management remained with the State and Territory governments, who can allow other parties to access and use water for a variety of purposes – irrigation, industrial use, mining, servicing rural and urban communities, or for amenity values.

However, water issues are of considerable interest and importance to the Australian Government because of the impact across state boundaries and the role of natural resources in sustaining agricultural enterprises, exports and services. Today, state and territory governments develop broad-based water plans, in consultation with the community, to share the water between economic, social and environmental interests. The plans commonly aim to ensure the long-term sustainability of the resource at the catchment or groundwater management unit scale. State water authorities generally manage the release of water from headworks (dams, weirs) and deliver bulk water to rural customers, water retailers or irrigation water providers. There are 22 irrigation water providers (usually trusts, companies or statutory authorities) supplying water for irrigation and some rural towns and about 300 urban water utilities.

The Council of Australian Governments – a national approach

Yet water is clearly a national issue, requiring national leadership and coordination. The primary mechanism for achieving this is through the Council of Australian Governments (COAG). COAG comprises our Prime Minister and each of the chief Ministers of the states and territories – effectively the equivalent of having the US President and each of the governors of the states together in a decision-making forum. It convenes to deal with nationally significant issues such as health and national security.

Water has also been a long-standing issue with a significant COAG agreement in 1994 to a water reform framework that recognised that better management of Australia's water resources was truly a national issue. The 1994 reforms aimed to promote good water management practices and ensure the development of strategies to promote water uses that ensure the long-term. On the ground, this meant the separation of water access entitlements from land titles, separating the functions of water delivery from that of regulation and making explicit provision for environmental water. The 1994 reforms also included changes to water pricing and allocations to better reflect the scarcity of supply.

States and territories have made considerable progress towards more efficient and sustainable water management. Each state's performance, in regard to these reforms is assessed by the National Competition Council – as for other competition reform areas such as electricity reform - and as a result of this assessment, the Australian Government makes payments to the states and territories based on satisfactory progress.

Despite the progress, there is a wide variation in water reforms between regions and jurisdictions and questions remain over the legal security of water entitlements. During this time, the allocation of water for irrigation has grown on an ad hoc basis with the outcome that there are now 39 different types of water licenses.

Critically, investment in new, more water efficient production systems was still being hampered by uncertainty over the long-term access to water in some areas. Markets had not reached their potential in scope or scale. Water trading was hindered by the complexities of different water product specifications, cumbersome administrative arrangements, lack of up-to-date market information and the policies of some water corporations that restrict license holders from permanently trading their water to other users outside their district. Furthermore, there was significant concern over the pace of securing adequate water for environmental purposes and adaptive management arrangements to ensure the ecosystem health of our river systems.

THE NATIONAL WATER INITIATIVE

In August 2003, COAG agreed to develop a National Water Initiative (NWI) in recognition of the continuing national imperative to increase the productivity and efficiency of Australia's water use, the need to service rural and urban communities, and to ensure the health of river and groundwater systems by returning all systems to environmentally sustainable levels of extraction. After 10 months of negotiation, the details of the NWI were further developed into an Intergovernmental Agreement (the Agreement) that was signed in June 2004 by COAG governments, with the exception of Western Australia and Tasmania.

The NWI will provide a truly national system and a framework for action on water management to be implemented by signatory governments over the next 10 years. It will provide greater certainty for investment and the environment and to ensure Australia's water management regimes are able to deal with change responsively and fairly. The NWI will provide:

- improved investment certainty;
- improved environmental outcomes;
- greater permanent trading;
- more sophisticated, transparent and comprehensive water planning;
- efficient management of water in urban environments;

- comprehensive and accountable implementation and review mechanisms; and
- community partnerships

Improved investment certainty

More confidence for investments in the water industry will be provided through more secure water access entitlements. Water entitlements will generally be defined as an open-ended or perpetual access to a share of the water resource that is available for consumption as specified in a water plan. Further, a risk assignment framework has been put in place that clearly and fairly assigns the risks for future reductions in the availability of water for consumptive use.

Overallocated water systems are to be returned to sustainable levels of use in order to meet environmental outcomes, with substantial progress by 2005 in systems already identified as overallocated, and in all systems by 2010. This is a key outcome for the sustainable use of water resources and will also provide greater water supply certainty into the future. Further, the NWI provides for assistance to affected regions on a case-by-case basis where significant adjustment issues arise.

Improved environmental outcomes

Environmental objectives for particular water resources will be more explicitly described, with statutory obligations on governments to provide sufficient water and suitable management arrangements to ensure those outcomes are achieved. Key elements of the NWI include:

- improved specification of the environmental outcomes to be achieved for particular water systems;
- improved accountability arrangements for environmental managers; and
- statutory recognition for environmental water.

Greater permanent trade

A key objective of the NWI is to ensure more profitable use of water through an improved capacity for and facilitation of water trade in connected systems. NWI measures to achieve this include:

- the removal of institutional barriers to trade in water, including a phased removal of barriers to permanent trade out of water irrigation areas in the southern Murray-Darling Basin;
- better and more compatible registry arrangements;
- better monitoring, reporting and accounting of water use;
- national standards for water accounting, reporting and metering; and
- improved public access to information on trade.

More sophisticated, transparent and comprehensive water planning

Improved planning regimes will be implemented to ensure key issues such as the interaction between surface and groundwater systems and the provision of water to meet specific environmental outcomes are accounted for. In addition, where a catchment is at, or close to, its sustainable level of water allocation, the NWI proposes regional/catchment scale assessments of the level of water likely to be intercepted through any new or changed land use. Where such new activities are likely to intercept significant volumes of water, a water access entitlement will be required.

Efficient management of water in urban environments

Better and more efficient management of water in urban environments will be achieved through the increased use of recycled water and stormwater. Third party access to water supply and sewage infrastructure will be reviewed and new minimum water efficiency standards and mandatory labelling of household appliances will be established. National guidelines for water sensitive urban design will be developed.

Implementation and Review Mechanisms

The NWI Intergovernmental Agreement includes a detailed timeline for implementation including requiring jurisdictions to develop implementation plans by the middle of 2005 and to have made substantial progress on implementation by 2010. A comprehensive national set of NWI performance indicators will be developed and commencing in 2005, jurisdictions will report annually on their progress to COAG. A significant step is the establishment of a new National Water Commission (NWC). The NWC will be an expert-based independent body established within the Australian Government and will provide comprehensive and factual assessments of progress on water reform to COAG.

Role of community partnerships and the NWI

As managers of 60 per cent of land and 70 per percent of diverted water, farmers are crucial to the achievement of the Australian Government's natural resource management goals. The NWI is an action plan for reform. However, without the commitment of all levels of government, the community and individual farmers through partnerships it will simply remain a plan for reform. Areas in which partnerships will be developed include:

- the development, implementation and periodic review of water plans;
- mechanisms for addressing overallocated systems and any significant adjustment issues that may arise; and
- other areas where significant decisions are made that may affect the security of water access entitlements or the sustainability of water use.

To facilitate the involvement of stakeholders, jurisdictions are required to provide accurate and timely information about the implementation of water plans and other relevant issues.

MURRAY DARLING BASIN – INSTITUTIONAL ARRANGEMENTS FOR THE MANAGEMENT OF SHARED WATER RESOURCES

This paper notes earlier, the economic importance of the Murray Darling Basin. The Basin crosses 5 jurisdictional boundaries and covers much of southeastern Australia. Water sharing has been an issue for nearly 100 years. This situation has parallels with the Colorado River Water Agreement and Republican River Compact Settlement amongst others, and is worth documenting here.

In 1915 the first River Murray Waters Agreement was reached between southern Basin states. In 1992 the Australian, New South Wales, Victorian and South Australian governments signed a new Murray-Darling Basin Agreement *"to promote and co-ordinate effective planning and management for the equitable efficient and sustainable use of the water, land and other environmental resources of the Murray-Darling Basin."*

The Murray-Darling Basin Act of 1993 was afforded the Agreement full legal status and all the signatory governments enacted identical legislation. Queensland also became a signatory in 1996 and in 1998, the Australian Capital Territory formalised its participation in the Agreement through a Memorandum of Understanding. The Agreement established a number of new institutions at the political, bureaucratic and community levels to underpin its implementation:

<u>The Murray Darling Basin Ministerial Council</u>. The Ministerial Council comprises the Ministers (up to three per government) responsible for land, water and environmental resources within the governments of New South Wales, Victoria, South Australia, Queensland and the Australian Government. Being a political forum, the Ministerial Council has the power to make decisions for the Basin as a whole, based on a consensus of governmental opinion and policy across the Basin.

<u>The Murray Darling Basin Commission.</u> This is the executive arm of the Murray-Darling Basin Ministerial Council, responsible for advising the Ministerial Council on the use of the water, land and other environmental resources of the Basin. It comprises an independent President, two Commissioners from each government and a representative of the ACT Government. Commissioners are normally chief executives and senior executives of the agencies responsible for management of land, water and environmental resources in the represented governments.

The Commission is an autonomous organisation equally responsible to the governments represented on the Ministerial Council and the Council itself. It is not a government department, nor a statutory body of any individual government. The Commission undertakes works and measures at the direction of the Ministerial Council, and initiates, supports and evaluates integrated natural resources management across the Basin.

Community Advisory Committee. A Community Advisory Committee – affectionately known as the 'CAC', advises the Ministerial Council on critical natural resource management issues. CAC was first established in 1986 and comprises a formally appointed independent Chairman and 20 members. Members are appointed for four years and are selected on the basis of their skills, expertise and their networks throughout the Basin.

River Murray Water. River Murray Water was established as an internal business division of the Murray-Darling Basin Commission in 1998. The primary services provided are: water storage and delivery; salinity mitigation such as the operation of salinity mitigation schemes; navigation; recreation and tourism; and other services such as hydro-power.

Murray-Darling Basin Initiatives

The River Murray 'Cap' on diversions. One of the most fundamental and important Basin water reform initiatives was the introduction in 1997of a 'Cap' to prevent any increase in diversions from the Murray River. A Cap was instituted when it was recognised that further diversions would undermine the reliability of existing water entitlements and exacerbate environmental problems.

Overall, the Cap has provided positive economic and social benefits to the irrigation community and is a major step in ensuring the sustainability of the River Murray. To illustrate this, the Cap, coupled with tradable water entitlements has allowed water to move to higher value and more productive uses, supporting a significant expansion in the wine industry over the last decade. There has been a 67% increase in production in South Australia's River Murray vines region. In the Sunraysia district of New South Wales, the area of land under grape production has increased by 2,400 hectares. Vineyard establishment requires a high level of investment and this increase in production would not have been possible without access to a permanent and secure water supply made possible by the Cap and an ability to trade entitlements.

The Living Murray 'First Step' and Murray Darling Basin Intergovernmental Agreement. In November 2003 the Murray Darling Basin Ministerial Council, (with the exception of Queensland) agreed to a 'Living Murray First Step' initiative, aimed at achieving specific environmental objectives and outcomes for six significant ecological assets along the River Murray. The sites include: the

Barmah-Millewa Forest; Gunbower and Koondrook-Perricoota Forests; Hattah Lakes; Chowilla floodplain (including Lindsay-Wallpolla); the Murray Mouth, Coorong and Lower Lakes; and the River Murray Channel. The achievement of environmental outcomes will be achieved through the timing of the water delivery to these sites, making the most of flooding events, and a parallel Aus$120 million program of infrastructure improvements. . This integrated approach will ensure the best possible use of available water towards achieving the objectives.

In addition to the June 2004 agreement to the NWI, COAG also agreed to a framework for funding of Aus$500 million over five years to address water overallocation in the Basin. This Agreement established arrangements for the recovery and management of water for the Living Murray First Step decision and to address other water overallocation issues in the Basin. Water recovered under this Agreement will be held permanently within the water allocation and access entitlement frameworks of the Parties and will have the security, reliability and access characteristics necessary to achieve the environmental outcomes agreed.

Water recovery will be achieved through a matrix of options, including water use efficiency and through the purchase of water in the market from willing sellers and must be agreed by all Parties to the Agreement. There will be no forced reduction in entitlements. The social and economic effect of this program's water recovery on rural communities and on the achievement of the environmental objectives will be carefully monitored.

CONCLUSION

Water is clearly part of Australia's natural capital, serving a number of important productive, environmental and social objectives. Australia's water resources are highly variable, reflecting the range of climatic conditions and terrain nationally. In addition, the level of development in Australia's water resources range from heavily regulated working rivers and groundwater resources, through to rivers and aquifers in almost pristine condition. The national importance of an agreement on the balance between consumptive use and the environment cannot be denied. The NWI is arguably the most important natural resource decision we have made as a nation. Taken together, the 1994 COAG reforms, the NWI, the framework for addressing the over-allocation of water in the Basin, and the Living Murray 'First Step', will take us far in reaching our goals of a nationally compatible water market, a regulatory and planning based system that can optimise economic, social and environmental outcomes, increased productivity and efficiency of water use, sustainable rural and urban communities; and ensuring the health of river and groundwater systems.

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MANAGING CONFLICTS ON THE LOWER AMERICAN RIVER – USE OF WATER RIGHTS FOR INSTREAM BENEFICIAL USES, A CASE STUDY

Leo Winternitz[1]

ABSTRACT

The lower American River, located in Sacramento County, California, provides important aquatic habitat, a high-quality water source, a critical floodway and a spectacular regional parkway. It is also a key water source for the Central Valley Project, which provides irrigation water to three million acres of the country's most productive agricultural lands. The River supports 43 species of fish, including fall run Chinook salmon and steelhead, currently listed by the Federal and State governments as threatened.

The Sacramento region's population is expected to double to over two million people in the next 30 years. Water demand to meet a growing population, including increased demand for River water outside the region will result in additional stress on a system that already suffers from low flow and high river temperatures. A flow standard adopted by the State's regulatory water right agency in 1958 was deemed inadequate by the same agency in 1990 to protect beneficial instream uses.

In 1993, regional stakeholders decided that new methods were needed to avoid water shortages, environmental degradation, continued groundwater contamination and limits to economic prosperity. After six years of interest-based negotiations, 40 stakeholder organizations approved a comprehensive Water Forum Agreement in 2000. The Agreement allows the region to meet its needs in a balanced way by implementing a comprehensive package of linked actions.

One of these actions is the development of a new flow standard for the American River. Included in the standard will be a provision, agreed to by the region's water purveyors that makes graduated quantities of their entitled surface water supplies available to the River for instream, aquatic purposes in drier years. To provide for continued water supply reliability during these drier years, these purveyors will be replacing their surface water supplies with groundwater and enforcing more stringent water conservation programs. The Water Forum Agreement allows for the transfer or marketing of the surface water after it has provided for instream beneficial uses. This helps protect the economic interests of the water purveyors and provides them a funding source for development of infrastructure associated with the use of groundwater.

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INTRODUCTION

The American River originates in the Sierra Nevada and flows westward to its confluence with the Sacramento River (Figure 1). In 1848, John Marshall discovered gold in this River, and it was between the American and Sacramento rivers where the capitol of California was established and now prospers. In 1955, Folsom Dam was constructed to provide flood protection for the Sacramento Valley. With a maximum capacity of about 1 million acre-feet, it has become the primary source for the region's water supply. Nimbus Dam, located immediately downstream, was constructed to serve as an afterbay.

In the last 20 years, the American River has been the focus of intense water development activities. The biggest stumbling block to balanced water solutions is that individual groups – water purveyors, environmentalists, local governments, business groups, agriculturalists and citizen groups – were independently pursuing their own water objectives, with little success. In many cases, competition among groups generated protests, lawsuits and delay. Even though $10 million had been spent pursuing single purpose solutions, there was little to show for these fragmented efforts. Gridlock had hit the region's water solutions.

Water Issues Facing the Region

The unresolved contentious water issues facing the region included:

Water Shortages – Unless adequate water supplies were made available, many existing residents, businesses, and farmers would continue to suffer shortages during California's periodic droughts. Water shortages limit economic development and planned growth. Population is expected to increase in the region by 1 million people over the next 30 years.

Drinking Water Reliability at Risk – In Sacramento County there are 24 water purveyors having every combination of water rights and entitlements. Some water purveyors obtain all of their water from surface sources; others rely solely on groundwater, and others have the capability to use either. There are disadvantages to having only one source of supply. The purveyors recognized that to provide for water supply reliability, they needed to have multiple sources of water.

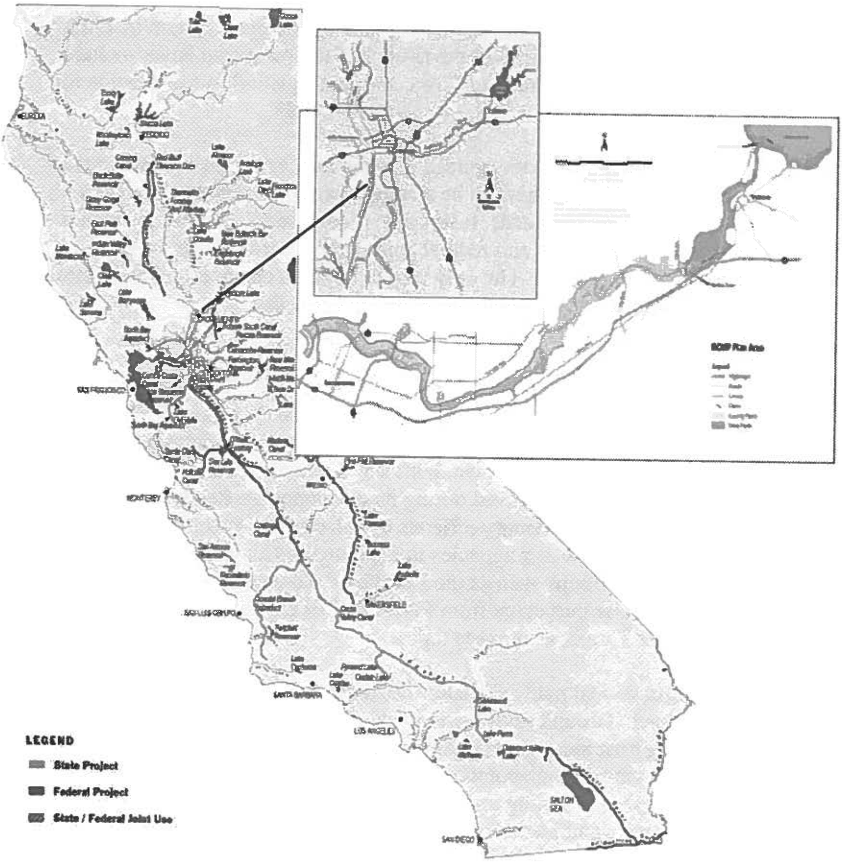

Figure 1. Map of Lower American River
(Including Folsom Reservoir and Nimbus)

Groundwater Reliability Threatened – Over reliance on groundwater in some areas had lowered the water table as much as 90 feet. Sustainable yields for the groundwater basin needed to be developed. In addition, past actions such as processes to dispose of industrial waste had contaminated significant areas of the groundwater basin resulting in the closure of over a dozen municipal drinking water wells within Sacramento County.

American River – The American River is nationally recognized for its beauty, fishery, and recreation. The 23 miles of the American River below Nimbus Dam consists of a parkway incorporating 4,000 acres of land connected to a series of 14 connected parks. The River was designated as a recreational river under the

National Wild and Scenic Rivers Act in 1981 and by the State system in 1982. Issues affecting the sustainability of the fishery of the American River include high water temperatures, fluctuating flows, and inadequate flows to provide for instream habitat conditions.

Since the early 1990's, it was recognized that any answer to this complex set of interrelated problems would have to be a comprehensive solution addressing different circumstances and needs. It was also recognized that solutions would require a series of local, state and federal approvals; environmental impact reports, and state water rights. The only way to obtain a comprehensive solution would have to be through a community consensus process.

Creation of the Water Forum

In 1991, the City and County of Sacramento formed the City-County Office of Metropolitan Water Planning (CCOMWP) to discuss regional solutions. The Office released a five-year water plan, but local water purveyors rejected it because they had not been involved during its development. Realizing a broader effort was needed; city and county officials established the Water Forum in 1993. Early members included water agencies in Sacramento County, environmental groups, other citizen groups such as the League of Women Voters, and business leaders. In 1995, water purveyors from Placer and El Dorado Counties joined creating the Water Forum, as it exists today.

Guided by a professional paid facilitator/mediator, six years of negotiations and discussions ensued. Ground rules were quickly established, and the first year was spent on building trust among participants not by negotiating, but by fact-finding and education on various viewpoints. The Water Forum process consisted of five interconnected phases: planning and assessment (determining whether the parties wanted to collaborate and identifying the issues), organization (training people in interest-based negotiations and establishing ground rules), education, negotiation/resolution of issues, and implementation.

Ultimately, participants were forced to move beyond their demands or historic positions, and focus on the underlying reasons (interests) behind both their own and their adversaries' concerns; a process known as interest-based negotiations. This development allowed participants to define areas for agreement, determine issues for trade-offs and draft language that would assure them of obtaining something in return for the other side receiving something else. For example, water purveyors wanted increased surface water diversions. In exchange, environmentalists got surface water for the American River in dry-year years, an improved lower American River flow standard, and water conservation programs and habitat projects. Assurances were built into the Agreement guaranteeing that all this would happen.

In April 2000, six years after its formation and after tens of thousands of hours of research and negotiations including a draft and final environmental impact report, the Water Forum Agreement was created and signed by 40 stakeholder organizations representing public interests, environmental interests, business interests, and water interests (Table 1). Creation of the Water Forum Agreement, which is to last to the year 2030, allowed the Sacramento region for the first time, to share a common vision on the use and protection of the region's water supply including the American River.

THE SEVEN ELEMENTS OF THE AGREEMENT

The Water Forum Agreement is predicated on two co-equal objectives:

1. Provide a safe and reliable water supply for the Sacramento Region's economic health and planned development to the year 2030; and

2. Preserve the fishery, wildlife, recreational, and aesthetic values of the Lower American River.

In signing the Agreement, signatories approved an integrated package of seven actions to benefit water supply and fish. The Agreement also recognized that some water purveyors have long-term surface water entitlements in excess of demands projected for the term of the Water Forum Agreement. However, all signatories recognized that nothing in the Agreement is intended to call for a reduction or forfeiture of existing surface water entitlements. Groundwater rights are similarly recognized.

The seven elements of the Water Forum Agreement are:

1. Increased surface water diversions – All signatories agreed to support the current and increased water diversions specified in the water purveyors' specific agreements to avoid shortages and allow for expected growth. (Table 2) (pp. 8-10 of WFA). It is envisioned that American River diversions by water purveyors in the region will increase from the current level of about 216,500 acre feet annually to about 481,000 acre feet annually.

   All signatories also agreed to support the facilities needed to divert, treat and distribute the water. Support for increased diversions is linked to the suppliers' endorsement and participation in each of the seven elements of the Agreement.

Table 1. Water Forum Agreement Signatories

Water Forum Agreement Signatories

Representatives of these organizations negotiated the recommendations and signed the Water Forum Agreement:

Public Interests

1. City of Sacramento
2. County of Sacramento
3. League of Women Voters of Sacramento
4. Sacramento County Alliance of Neighborhoods
5. Sacramento County Taxpayers League
6. Sacramento Municipal Utility District (SMUD)

Environmental Interests

7. Environmental Council of Sacramento
8. Friends of the River
9. Save the American River Association, Inc.
10. Sierra Club - Mother Lode Chapter – Sacramento

Business Interests

11. Associated General Contractors
12. Building Industry Association of Superior California (BIA)
13. Sacramento Association of Realtors
14. Sacramento Metropolitan Chamber of Commerce
15. Sacramento-Sierra Building & Construction Trades Council

Water Interests

16. Arcade Water District (later consolidated with Northridge Water District to form the Sacramento Suburban Water District. The Arcade portion of the new district is still working on a purveyor-specific agreement)
17. Arden Cordova Water Service
18. Carmichael Water District
19. Citizens Utilities Company of California (now California American Water Company)
20. Citrus Heights Water District
21. City of Folsom
22. City of Roseville*
23. Clay Water District
24. Del Paso Manor Water District
25. El Dorado County Water Agency* (operates under a "procedural agreement")
26. El Dorado Irrigation District* (operates under a "procedural agreement")
27. Fair Oaks Water District
28. Florin County Water District
29. Galt Irrigation District
30. Georgetown Divide Public Utility District* (operates under a "procedural agreement")
31. Natomas Central Mutual Water Company
32. Northridge Water District (later consolidated with Arcade Water District to form the Sacramento Suburban Water District)
33. Omochumne-Hartnell Water District
34. Orange Vale Water Company
35. Placer County Water Agency*
36. Rancho Murieta Community Services District (operates under a "procedural agreement")
37. Rio Linda/Elverta Community Water District
38. Sacramento County Farm Bureau
39. Sacramento Metropolitan Water Authority (now the Regional Water Authority)
40. San Juan Water District

* Member of Foothills Water Caucus

Three water suppliers chose not to participate in the Water Forum: Elk Grove Water Works, Fruitridge Vista Water Co., and the city of Galt.

2. Actions to meet customer's needs while reducing diversion impacts in drier years – Increased surface water diversions will cause significant impacts to aquatic resources in the American River particularly in the drier years. To help mitigate for this impact, water purveyors agreed to reduce their surface diversions in the drier and driest years (see Table 2). To provide for water supply reliability during these years, purveyors will rely on conjunctive use of groundwater basins consistent with the sustainable yield objectives, using other surface water resources, reoperation of reservoirs upstream of Folsom Dam, increased water conservation, and water reclamation.

3. An improved pattern of fishery flow releases from Folsom Reservoir – Since construction of Folsom Dam and Reservoir, the U.S. Bureau of Reclamation's (Bureau) releases were legally constrained by the outdated fish flow requirements of the State Water Resources Control Board (State Board) Decision 893, which incorporates the existing flow standard for the lower American River. Until recently, the Bureau released water from Folsom Reservoir on a pattern that did not match the life cycle needs of fall run Chinook salmon and steelhead trout. Since Decision 893 was adopted, the naturally producing (as opposed to hatchery produced) lower American River salmonid fishery has significantly declined.

   Increased surface water diversions in this Agreement will be permanent. Therefore, it is essential that the Bureau on a permanent basis also implement an improved pattern of fish flow releases. Signatories agreed to work with the Bureau and the State Water Resources Control Board to develop a new flow standard for the River to release water from Folsom Reservoir at critical times in the life cycle of the fall run Chinook salmon and steelhead trout.

Table 2. 1995 and Proposed Year 2030 Surface Water Diversion

1995 AND PROPOSED YEAR 2030 SURFACE WATER DIVERSIONS

Note: The diversions described below, combined with the dry year actions, will meet each supplier's customers' needs to the year 2030.

AMERICAN RIVER DIVERSIONS—UPSTREAM OF NIMBUS

WATER SUPPLIER/ ORGANIZATION	1995 BASELINE (1)	2030 DIVERSION (wet/ave years)	2030 DIVERSION (drier years)	2030 DIVERSION (driest years) (2)
City of Folsom	20,000 AF (19)	34,000 AF (3)	Decreasing from 34,000 AF to 22,000 AF (4)	20,000 AF (5)
Northridge Water District (17)	0 AF	29,000 AF (9)	0 AF (10)	0 AF
Placer County Water Agency (6) (7) [Subject to resolution of remaining issues (21)]	8,500 AF	35,500 AF (3)	Continue to divert 35,500 AF, with a replacement to the river equivalent to their drier diversions above baseline. The drier the year, the more water would be replaced up to 27,000 AF (4) (20)	Continue to divert 35,500 AF, with a replacement of 27,000 AF to the river. (20)
City of Roseville (7)	19,800 AF	54,900 AF (3)	Decreasing from 54,900 AF to 39,800 AF with a replacement to the river equivalent to their drier diversions above baseline. The drier the year, the more water would be replaced up to 20,000 AF (4)	Continue to divert 39,800 AF, with a replacement of 20,000 AF to the river.

1995 AND PROPOSED YEAR 2030 SURFACE WATER DIVERSIONS (continued)

Note: The diversions described below, combined with the dry year actions, will meet each supplier's customers' needs to the year 2030.

AMERICAN RIVER DIVERSIONS—UPSTREAM OF NIMBUS

WATER SUPPLIER/ ORGANIZATION	1995 BASELINE (1)	2030 DIVERSION (wet/ave years)	2030 DIVERSION (drier years)	2030 DIVERSION (driest years) (2)
San Juan WD & Contractors in Sacramento County (Citrus Heights WD, Fair Oaks WD, Orange Vale Water Co)	44,200 AF (6)	57,200 AF (3)	Decreasing from 57,200 to 44,200 AF (4)	44,200 AF
San Juan WD (Placer County)	10,000 AF	25,000 AF (3)	Decreasing from 25,000 to 10,000 AF (4)	10,000 AF
South Sacramento County Agriculture (includes Clay WD, Omochumne-Hartnell WD, Galt ID, & Sacramento County Farm Bureau)	0 AF	35,000 AF (9)	0 AF (10)	0 AF
SMUD	15,000 AF (11)	30,000 AF (3)	Decreasing from 30,000 to 15,000 AF (4)	15,000 AF

1995 AND PROPOSED YEAR 2030 SURFACE WATER DIVERSIONS (continued)

AMERICAN RIVER DIVERSIONS—BETWEEN NIMBUS & THE MOUTH

WATER SUPPLIER/ ORGANIZATION	1995 BASELINE (1)	2030 DIVERSION (wet/ave years)	2030 DIVERSION (drier years)	2030 DIVERSION (driest years) (2)
Carmichael WD (18)	12,000 AF	12,000 AF	12,000 AF	12,000 AF
City of Sacramento	50,000 AF	310 CFS (12) (13)	50,000 AF (15)	50,000 AF

SACRAMENTO RIVER DIVERSIONS

WATER SUPPLIER/ ORGANIZATION	1995 BASELINE	2030 DIVERSION (wet/ave years) (14)	2030 DIVERSION (drier years) (14)	2030 DIVERSION (driest years) (14)
City of Sacramento	45,000 AF	290 CFS (13)	290 CFS (13)	290 CFS (13)
County of Sacramento	0 AF	Up to 78,000 AF (16)	Up to 78,000 AF (16)	Up to 78,000 AF (16)
Placer County Water Agency (6) [Subject to resolution of remaining issues (21)]	0 AF	35,000 AF	35,000 AF	35,000 AF
Natomas Central Mutual Water Co. within Sacramento County	53,000 AF	45,600 AF	45,600 AF	45,600 AF

1995 AND PROPOSED YEAR 2030 SURFACE WATER DIVERSIONS — NOTES

1. Baseline: Baseline means the historic maximum amount of water that suppliers diverted from the American River in any one year through the year 1995 or in certain appropriate instances other amounts specified in a purveyor's specific agreement. Clarifications pertaining to the San Juan Water District, SMUD and the City of Folsom are noted in footnotes 8, 11, and 19.
2. Driest Years (i.e. Conference Years): Years when the projected March through November Unimpaired Inflow to Folsom Reservoir is less than 400,000 acre feet. Conference years are those years which require diverters and others to meet and confer on how best to meet demands and protect the American River.
3. Wet/Ave Years: As it applies to these diverters, years when the projected March through November Unimpaired Inflow to Folsom Reservoir is greater than 950,000 acre feet.
4. Drier Years: As it applies to these diverters, years when the projected March through November Unimpaired Inflow to Folsom Reservoir is less than 950,000 acre feet.
5. In the Conference Years the City of Folsom would reduce diversions by an additional 2,000 acre feet below its baseline to 18,000 AF through additional conservation to achieve recreational benefits to Folsom Reservoir and fishery benefits to the Lower American River.
6. PCWA would receive support for an American River diversion of 35,500 AF (8,500 AF existing and 27,000 AF additional) in wetter and average years and a new Sacramento/Feather Diversion of 35,000 AF. PCWA is willing to exchange 35,000 AF of its American River water for Sacramento and/or Feather River water provided the terms of such exchange do not result in any diminution of PCWA's water supply or an increased cost to PCWA.
7. For these suppliers, some or all of their water supply diverted from the American River or Folsom Reservoir in the drier and driest years could be replaced with water released from the Middle Fork Project Reservoirs by reoperating those reservoirs. Reoperation of the MFP reservoirs causes the reservoirs to be drawn down below historical operational minimum pool volumes.
8. The baseline for SJWD and their wholesale service area within Sacramento County is the full amount of their entitlements (CVP contract and water rights) which they exercised in 1995.
9. Wet/Ave Years: As it applies to these diverters, years when the projected March through November Unimpaired Inflow to Folsom Reservoir is greater than 1,600,000 acre feet.
10. Drier Years: As it applies to these diverters, years when the projected March through November Unimpaired Inflow to Folsom Reservoir is less than 1,600,000 acre feet.
11. The baseline for SMUD is the 1995 diversion amount which reflects the shut down of Rancho Seco Power Plant.
12. Wet/Ave Years: As it applies to the City of Sacramento, time periods when the flows bypassing the E. A. Fairbairn Water Treatment Plant diversion exceed the "Hodge flows."
13. For modeling purposes, it is assumed that the City of Sacramento's total annual diversions from the American and Sacramento River in year 2030 would be 130,600 AF for use within the City limits.
14. As it applies to these diverters, there is no Water Forum limitation to diversions from the Sacramento River.

The Hodge Flows: Hodge flows are the result of Judge Hodge's ruling in the 17-year lawsuit between the East Bay Municipal Utility District and the Environmental Defense Fund et al, over water diversions in the American River. In 1987, Judge Hodge issued his decision that balanced the needs of the fishery with EBMUD's contractual entitlement to American River water. These flows have come to be know as the Hodge flows.

1995 AND PROPOSED YEAR 2030 SURFACE WATER DIVERSIONS — NOTES (continued)

15. Drier Years: As it applies to the City of Sacramento, time periods when the flows bypassing the City's E. A. Fairbairn Water Treatment Plant diversion do not exceed the "Hodge flows." Within its existing capacity, the City can divert from the American River 155 cfs in June, July and August, 120 cfs in January through May and September, and 100 cfs in October through December.
16. The total for the County of Sacramento (78,000 AF) represents 45,000 AF of firm entitlement and 33,000 AF of intermittent water. The intermittent supply is subject to reduction in the drier and driest years. To reduce reliance on intermittent surface water, the County of Sacramento intends to pursue additional firm supplies.
17. Northridge Water District (NWD) and other signatories have agreed that for an interim ten year period, NWD would be able to divert PCWA water in years when the projected March through November Unimpaired Inflow to Folsom Reservoir is greater than 950,000 acre feet. After the ten-year period, unless the State Water Resources Control Board issues a subsequent order, NWD will divert up to 29,000 acre feet of water from Folsom Reservoir under the NWD-PCWA contract only in years when the projected March through November unimpaired inflow into Folsom Reservoir is greater than 1,600,000 AF.
18. Carmichael Water District will divert and use up to their license amount of 14,000 acre feet. By the year 2030, it is most likely that the water demand for the District will be reduced to their historic baseline level of 12,000 acre feet by implementation of Urban Water Conservation Best Management Practices. Signatories to the *Water Forum Agreement* acknowledge and agree that CWD shall not relinquish control of or otherwise abandon the right to any quantity it has foregone delivery and/or diversion of under this *Agreement*, and shall retain the right (if any) to transfer that water for other beneficial uses, after that water has served its purpose of assisting in the implementation of the Improved Pattern of Fishery Flow Releases, for diversion or rediversion at, near, or downstream of the confluence of the Lower American River and the Sacramento River. The signatories also recognize that any such transfer of water by CWD must be in accordance with applicable provisions of federal and state law.
19. This is an agreed upon amount which is within the historic diversion data and is equivalent to Folsom's treatment capacity as of 1999.
20. Replacement of water to the river as a dry year action as provided in PCWA's specific agreement is contingent on PCWA's ability to sell this water to the Department of the Interior to meet Anadromous Fishery Restoration Program goals for the Lower American River or to other parties for their use after it flows down the Lower American River.
21. Remaining issues which are being negotiated are: 1) environmentalists' support for PCWA pumps at Auburn, 2) how water conservation Best Management Practice #5 (Large Landscape Water Audits and Incentives for Commercial, Industrial, Institutional and Irrigation Accounts) will be implemented, 3) environmentalists' support for conditions related to release of replacement water in drier and driest years.

4. Water conservation - Water conservation is expected to help produce additional supplies for the region's expected growth and reduce the need to increase surface water diversions and groundwater pumping. The water conservation element, fully implemented, is expected to reduce water demand by about 25 percent on a regional basis by the year 2030. Five separate actions were identified:
   - Installation of residential water meters, with the City of Sacramento's program voluntary only because the City's charter prohibits meters;
   - Full implementation of other water conservation programs by the start of the fourth year after signing of the Water Forum Agreement. These programs were adopted from the Statewide Memorandum of Understanding regarding Urban Water Conservation Best Management Practices, and have been customized by the Water Forum.
   - Public involvement through the establishment of citizen advisory committees for reach supplier;
   - Incorporation of individual water conservation plans into the official agreement;
   - Agricultural water conservation programs as required under the federal Central Valley Improvement Act.

5. Groundwater management – Groundwater supplies over half the water used in the region. The potential for continued over pumping and contamination pointed to the need for some type of groundwater management plan to protect the resource. This element provides a framework by which groundwater in the Sacramento region can be protected and used in a sustainable manner. It also provides a mechanism for coordination with those counties that share the groundwater basin.

   The groundwater element includes monitoring the amount of water withdrawn from the groundwater basin and the planned use of surface water in conjunction with groundwater. A key provision of this element includes recommendations on "sustained yield," which is the amount of water that can be safely pumped over a long period without damaging the aquifer. Agreed-upon annual sustainable yields for the three sub-areas of the groundwater basin were developed (Figure 2).

6. Water Forum Successor Effort (WFSE) – To ensure implementation of the many programs and projects in the Water Forum Agreement over the next three decades, signatories established a formal successor to oversee, monitor, and report on implementation. The Successor Effort

has no authority to govern or regulate, but its members meet six times a year to discuss progress and problems. Side meetings are also held on specific projects. The WFSE is supported by personnel from the CCOMWP.

WATER RIGHTS AND INSTREAM BENEFICIAL USES

A unique aspect of the Water Forum Agreement is the focus on long-term reliable water supply while providing protection for the aquatic resources of a major source of the supply, the lower American River. To provide for a reliable water supply, environmental and public organizations in the Sacramento region agreed to a 120 percent increase in surface water diversions over a 30-year period from a river that they felt had already been over-committed to the detriment of fish resources. Not only did they agree to the increased surface water diversions, but they also agreed to support the infrastructure and water contracts necessary to enable the diversions.

Protecting the Lower American River

In 1958, the State Water Resources Control Board adopted Water Right Decision 893 which allows the Bureau to operate Folsom Dam and Reservoir on the American River to provide for water for irrigation, municipal and industrial uses, hydroelectric power, recreation, water quality, flood control and fish protection. Biological, legal and institutional conditions have changed substantially since the State Board adopted this decision.

In 1984, the Alameda County Superior Court appointed the State Board as a referee in a lawsuit over the diversion of water from the American River (*Environmental Defense Fund v East Bay Municipal Utility District*) and directed the State Board to prepare a Report of Referee. After an extensive investigation, the State Board adopted the Report of Referee in 1988. In that report the State Board concluded that, the existing American River flow requirements do not provide an adequate level of protection to the uses in the River. In 1990, the State Board prepared a workplan to review water rights on the American River and to determine the appropriate flows to be maintained in the River. The State Board anticipated adopting a final order on improved flows in the River by November 1992. This work has never been completed.

In April 2000, when the Sacramento Region Water Forum Agreement was signed, water purveyors, in return for a reliable water supply including increased river diversions, agreed to support the adoption of an improved flow standard for the American River, and also agreed to reduce surface water diversions in certain dry years to enhance the water supplies that the Bureau has to manage at Folsom Lake to meet instream flow requirements. The Bureau has also pledged to work with the Water Forum to develop a proposal for modification of its permit to enhance flows in the River.

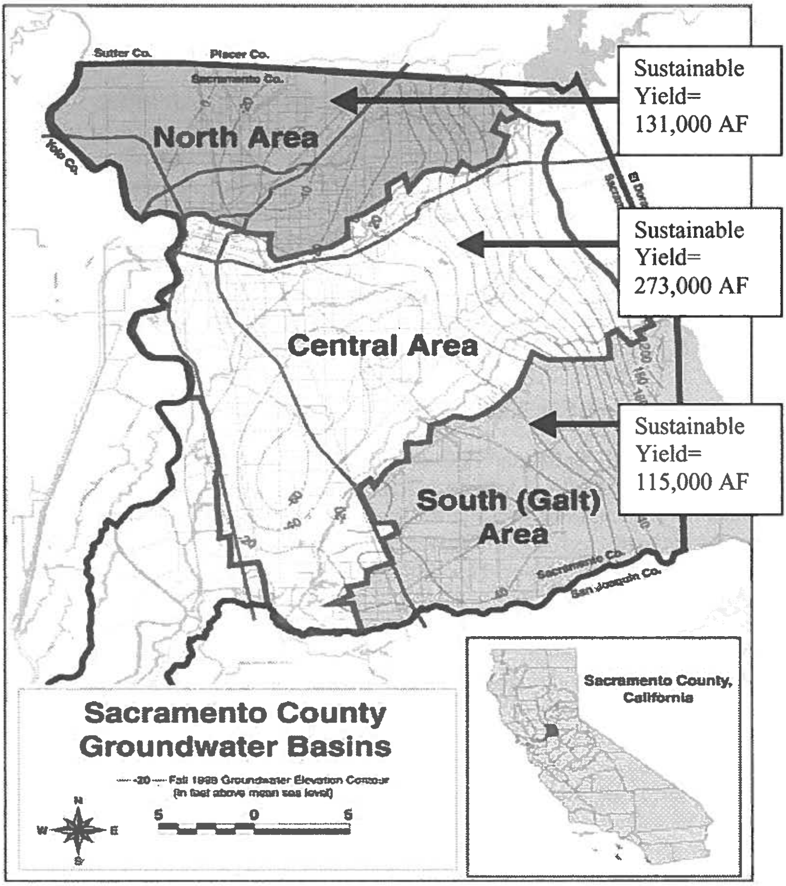

Figure 2. Sacramento County Groundwater Basins

Use of Water Rights for Instream Flows

Twenty-six water purveyors signed the Water Forum Agreement. Of these, 13 use water diverted directly from the American River. While the Agreement allows all purveyors to increase their surface water diversions in wet and average years from 1995 baseline levels to specific negotiated quantities consistent with water rights or contractual agreements through the year 2030, all except three purveyors (one of which is solely dependent on surface water, and the other two still have not completed agreement terms) have agreed to reduce their year 2030 diversion levels during drier years and back to their baseline amounts in the driest years. Baseline means the historic maximum amount of water that a purveyor diverted from the American River in any one year through the year 1995 or, in appropriate instances, other amounts negotiated. Water made available from the drier and driest year diversion reductions will be used to provide instream flows for the River's aquatic resources.

Water Forum Contribution to the American River

Table 3 illustrates the quantities of water made available to the American River during the drier years from water purveyor signatories to the Water Forum Agreement. Note that the table includes contributions of water in other than just dry years (1954, 1970, 1984).

This is because the year type (YT) used in the table is related to the larger Sacramento Valley Index while the year type used to determine the actual contributions from the purveyors is of the American River Basin. In these particular years, the American River Basin Index indicated a dry year condition but the Valley Index indicated wetter year conditions.

The table illustrates that significant contributions of water are being made available to the American River for instream aquatic purposes from Water Forum water purveyors. On average, about 25 percent of the time (19 of 72 years used in water resource modeling) about 44 thousand acre-feet will be made available to the River during the drier year types. The maximum made available in a critically dry year type is over 88,000 acre-feet. These quantities represent significant water amounts that will be used to protect fish. The water purveyors have reserved the right to market or sell this water to willing downstream buyers, but only after it has been released on a "fish-friendly" pattern to be determined by a group of state, federal and stakeholder biologists.

Contracts are now being developed with the Bureau to store dry year water at Folsom Reservoir, and make available this water when it is called for under the terms specified in the Water Forum Agreement.

Table 3. Estimated Water Forum Contribution to American River

AFA	WY	YT
88,175	1924	C
43,870	1931	C
22,218	1934	C
96,772	1976	C
88,175	1977	C
50,607	1988	C
6,580	1990	C
47,974	1959	BN
44,000	1962	BN
44,000	1966	BN
44,000	1968	BN
44,000	1972	BN
14,588	1939	D
22,510	1961	D
15,515	1981	D
58,115	1987	D
44,000	1954	AN
44,000	1970	W
44,000	1984	W

AFA = Acre Feet per Annum

WY = Water Year (Oct. 1 – Sept. 30)

YT = Year Type: (C = critical; BN = below normal; D = dry; AN = above normal; W = wet)

Dry Year Water Supply Reliability

The Water Forum Agreement recognizes that to provide for water supply reliability, particularly in the drier years when they have reduced their surface water diversions, water purveyors may need to take certain specific actions. In addition to extraordinary conservation measures, the Water Forum Agreement includes three alternative ways for purveyors to accomplish this objective.

The first would be to continue to meet their customers' needs in drier years through supply alternatives such as the increased use of groundwater. This action requires the development and implementation of a groundwater management program, including agreed-upon sustainable yields that guide quantities of groundwater used over a period. The sixth element of the Water Forum Agreement directly addresses these issues. Groundwater sustainable yields have been developed for each of the three sub-basins in the Sacramento region and a governing management structure has been developed for the north basin. Governing management structures are currently being developed for the central and south basins.

A second way to meet water supply reliability during the drier years would be through a release of replacement water upstream of Folsom Reservoir. This would be accomplished through re-operation of upstream reservoirs that currently provide for hydroelectric power generation and some water supply. The drier the year, the greater the amount of water that would be replaced. In the driest years, the amount of water replaced would be equivalent to the purveyor's increased diversions over baseline, or other amounts specified in the Agreement.

A third method that would allow purveyors to meet a portion of their needs is from diversions from the Sacramento River. Any Sacramento River diversion would avoid direct impacts on the American River.

CONCLUSIONS

The Water Forum Agreement lays out guiding principles for maximizing water supply in the Sacramento region while ensuring enough water flows down the American River to protect habitat for fish and other wildlife. However, even the Water Forum signatories themselves recognized that the Agreement itself does not guarantee a future free of water conflicts. That is why they wisely agreed to the seventh element of the Agreement, the Water Forum Successor Effort. The Water Forum Agreement does provide the tools and framework for managing issues as they arise in the future.

Since the Agreement was signed in April 2000, a number of positive actions have been accomplished that benefit both water supply and protection for the American River (Table 4). Water treatment plants have been expanded that allow for increased diversions of water – something that has not happened the last 20 years; a groundwater authority to manage the north area groundwater basin has been developed; a habitat management plan for the American River with funding for implementation of the plan has been approved, and an urban water temperature control device has been installed at Folsom Reservoir to benefit salmonids on the American River. Some other important work, like an updated flow standard for the American River, are still being developed.

Participants remain staunch supporters of the Water Forum process. They recognize that it cost more money initially to participate in a collaborative process, but they are now also beginning to realize the rewards.

Table 4. Water Forum Successes

WATER FORUM SUCCESSES
▪ Expansion of Water Treatment Plants for: ➢ City of Sacramento ➢ City of Folsom ➢ City of Roseville
▪ Development of the Sacramento Groundwater Authority
▪ Development and Implementation of the American River Corridor Management Plan
▪ Pump Station Construction and River Restoration in Auburn
▪ Construction for Urban Temperature Control Device at Folsom Lake
▪ Stakeholder Support for Acquisition of Additional Federal Water Supplies for Sacramento County
▪ Agreement Between East Bay Municipal Utility District and County of Sacramento for a Diversion on the Sacramento River

PROTECTION/TRANSFER OF CONSERVED WATER FROM THE SACRAMENTO VALLEY

Marc Van Camp[1]

ABSTRACT

The purpose of this paper will be to provide a brief summary of California Water Rights in order to identify the current pressures of conservation, efficiency, and transfers on water right holders in the Sacramento Valley. The effect of these pressures and relationships to the water right system of priority needs recognition. In order to evaluate the current pressures and the potential issues, a brief description of the Central Valley Project and the State Water Project and their relationship to the basic water rights held by numerous water right holders within the Sacramento Valley will be provided.

As the demand for water in the State of California approaches the supply available in an increasing number of years, the various issues related to water rights and the historical regulation of those water rights by priority are tested. A few key issues including water transfers, water conservation, and water use efficiency are causing pressure on water users that may not result in improved water management. In describing these issues, it will be necessary to identify the roles of the United States Bureau of Reclamation (Bureau of Reclamation) and the California Department of Water Resources (Department of Water Resources) as regulators, project operators, and water right holders.

Water right holders in the Sacramento Valley have come under increased pressure, whether perceived or real, to increase efficiency and conserve water. The use of efficiency as a regulatory tool and the effects of increased efficiency to areas in the Sacramento Valley have the potential to affect the sustainability of agriculture in certain areas and the long-term future of a water right holders right without certain precautions. These precautions can be undertaken through existing California law, specifically identified in Water Code Section 1011 which will be discussed and related to the issues identified above. The conflict of water use efficiency with environmental issues causes difficulties for water users to meet the demands of competing regulatory issues, even within a given regulatory agency. Identifying where these conflicts occur and pointing to existing rules and regulations may allow a water right holder to have a sense of security relative to these issues.

Some of the issues related to California water transfers that will be addressed include the conflicting criteria currently used in water transfers of surface water

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rights and ground water rights. A brief description of the current rules employed for water transfers will be provided together with possible conflicts relative to water rights.

This paper will provide insight into issues that are currently or will be soon facing water right holders in the Sacramento Valley due to the increasing pressure on the available water supply.

INTRODUCTION

Increasing pressures are being applied to our agricultural industry through various mechanisms. The continuing demand to increase efficient use of water for agricultural purposes is one of these pressures. This pressure is both direct, through compliance with water rights and contracts, and indirect through what appears to be an increasing trend to use irrigation efficiency as a regulatory tool. California's water right system is based on "reasonable and beneficial" use of water. It is important for those of us in the water management field to provide the appropriate technical tools to manage our valuable water resource without causing unnecessary pressures on existing water users that may result in inadvertent adverse impacts.

CALIFORNIA WATER RIGHTS

The California water right system includes both riparian and appropriative rights. Under the riparian doctrine, those lands that are, or have retained their contiguous nature to a water course, are entitled to divert and use the natural flow of that water course for reasonable and beneficial uses on that land.

On December 19, 1914, the California Water Commission Act was enacted and established our current system of prior appropriation, which is based on the concept of first in time, first in right. This system is administered through the California State Water Resources Control Board. The system created two classes of appropriative water rights, referred to as pre-1914 and post-1914 water rights. Pre-1914 appropriative water rights can be established through proof of past and continuous use or appropriate noticing. All three of the rights; riparian, pre-1914, and post-1914, are limited by reasonable and beneficial use. Appropriative water rights are established to document the maximum quantity of water an individual or entity is entitled to divert for use on a specified area of land. This process is commonly referred to as perfecting a water right. It is important to note these water rights are measured and regulated at the point of diversion from the water source identified. No regulation of the water right quantity occurs within the system or at the discharge end of the system. In fact, a water right holder whose water right was established based on some historical maximum diversion and that resulted in incidental tailwater, could later recapture and reuse the tailwater, and maintain diversions for use on the specified place of use. To further demonstrate or describe the nature of the water right system and regulation, I will use an example. A post-1914 water right is based on a documented recent historical maximum diversion from a source. This maximum diversion may have been made for a row crop with low on-farm efficiency, resulting in tailwater. This water right holder could change to a higher water consuming crop, such as rice, and install a recirculating pump to reuse and eliminate all tailwater to meet the crop water needs. This flexibility to change the crop choice and increase the reuse of tailwater is not restricted under the water right. Conversely, a water right perfected through irrigation of a low water consuming crop and having a high irrigation efficiency is restricted to that diversion rate and quantity. The water right diversion rate or quantity cannot be increased. Therefore, the water right would be inadequate to meet the needs of an equivalent acreage of a higher water consuming crop.

Many post-1914 water rights authorize diversion of irrigation return flow or tailwater resulting from upstream irrigation. The State Water Resources Control Board puts these water right holders on notice through terms of the water rights that the supply is not necessarily reliable and cannot be dictated or called upon based on the downstream water right. A form of the water right term that is contained in these water rights is as follows:

> "To the extent that water available for use under this license is return flow, imported water, or wastewater, this license shall not be construed as giving any assurance that such supply will continue."

Although the water rights for the Central Valley Project (CVP) and the State Water Project (SWP) may not include specific terms similar to the above, language in the permits and subsequent orders relative to the CVP and SWP clearly identifies the priority of area of origin needs and uses over the CVP and SWP exports, regardless of when an application for use within the area of origin was filed. Through these terms and the common understanding relative to return flow; the CVP and SWP, as water right holders, have no authority to dictate the level of return flow from upstream water right holders. A brief description of the CVP and SWP is provided in a subsequent section of this paper.

One strategy for a water user to conserve water and increase its irrigation efficiency is to reduce the occurrence and quantity of tailwater. In 1979, Water Code Section 1011 was enacted and provides protections to the water rights for those who reduce diversions through conservation efforts. Under this section of the water code, the reduction or cessation of water use resulting from conservation efforts shall be deemed to be reasonable and beneficial use. It is important to note that Water Code Section 1011 specifically identifies temporary land fallowing or crop rotation as water conservation efforts.

Section 1011 requires the water right holder to file reports to provide a means to document water conservation efforts in order to preserve the water right from possible forfeiture from non-use.

SACRAMENTO VALLEY

The Sacramento Valley is bounded by the Sierra Nevada Mountains on the east, and the Coastal Mountains on the west. On the northern end of the Sacramento Valley is the southern end of the Cascade Mountains; Mount Shasta. The Sacramento Valley extends southerly, below the State Capitol of Sacramento where it joins the Sacramento-San Joaquin Delta. The major water courses leading to the valley floor are from the north and the east. These water courses are the Sacramento River, Feather River, Yuba River, Bear River, and the American River. There also are numerous streams and creeks draining from the Sierra Nevada Mountains on the east side of the valley that contribute substantial quantities of water to the valley floor. There are numerous streams and creeks tributary to the valley floor from the west, that contribute a small, relatively insignificant portion of the water supply, especially during the normal irrigation season.

The major water courses in the Sacramento Valley are tributary to the Sacramento River. The Sacramento River headwaters, near the town of Mount Shasta City, are spring fed by the glaciers on Mount Shasta. The Sacramento River flows through the valley floor picking up flow from various tributaries before entering the Sacramento-San Joaquin Delta.

CVP/USBR AND SWP/DWR

The Bureau of Reclamation and the Department of Water Resources are water right holders for the purposes of their respective projects, the CVP and the SWP. These projects were developed for numerous purposes, one of which was to provide a secure and reliable water supply for water users, both upstream of and outside the Sacramento-San Joaquin Delta. In order to provide a significant portion of the project water supply, water is pumped to export areas. Both of the projects have storage facilities and the associated water rights above or upstream of the Sacramento Valley floor. These storage facilities have the ability to store significant quantities of water. In addition to having storage facilities and water rights at the upper end of the watershed, the CVP and SWP also operate diversion facilities from the Sacramento-San Joaquin Delta at the lowest or most downstream point of the water system. Having access to facilities at the upstream and downstream ends of the watershed provides these projects with an opportunity to optimize water use pursuant to the established water rights. However, a significant challenge to both the CVP and SWP is the protection of its water supply from illegal diversions between its uppermost and lowermost points of control on the system. The CVP and SWP, as water right holders, have the right to protect their interest in the water supply pursuant to their established water rights and other statutes.

The protection of CVP and SWP water for export becomes more complicated due to the Watershed Protection Statutes (Water Code 11460 et seq.) which establish a priority for use of natural flows to in-basin water users over those of the CVP and SWP for export. Protections to CVP and SWP have been provided for through a standard water right term known as "Term 91" that limits diversions by junior water right holders during certain dry hydrologic conditions. A detailed description of Term 91 is beyond the scope of this paper. When water transfers have taken place, Term 91 or a more conservative method of accounting has been undertaken to ensure no injury to the CVP and SWP export water users.

It is important to acknowledge, however, that the Bureau of Reclamation and the Department of Water Resources also have contracts with water right holders between their uppermost and lowermost point of control and facilities on the water system. In their roles as contract administrators, the Bureau of Reclamation and Department of Water Resources act as regulators over these water right holders, and unless clear direction is provided, can continue to apply certain pressure in the regulatory mode. This regulatory pressure typically comes through the Bureau of Reclamation's and the Department of Water Resources' ability to approve water transfers and through its requirements for water conservation as the contractor with entities in the Sacramento Valley.

CVP contractors within the Sacramento Valley are required to implement a water conservation plan pursuant to the Bureau of Reclamation's guidelines. The Sacramento River Settlement Contractors have been working with the Bureau of Reclamation to implement a Basin-Wide Water Management Plan, and are responding to the Bureau of Reclamation's development of regional criteria. Since the implementation of the Central Valley Project Improvement Act, the Bureau of Reclamation requires an evaluation of irrigation efficiency and has set a goal of 80% efficiency; without clear definition as to whether this efficiency is measured at the field, district, or sub-basin level. In addition, during recent contract renewal negotiations, the Bureau of Reclamation evaluated the water needs of various Sacramento River Settlement Contractors assuming a 80% district-wide efficiency. I am unaware of any analysis or evaluation justifying whether an 80% efficiency is appropriate or has a potential impact when considering the entire water system.

The CALFED Bay-Delta Program is a joint effort between State and Federal Agencies with the goal to develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta. The CALFED program, through its water use efficiency program, is reviewing and considering measurement of water at all turnouts from irrigation facilities within the Sacramento Valley. CALFED representatives believe this will improve irrigation efficiency and assist in meeting CALFED's stated goals. Whether these pressures are real or perceived by the agricultural community, significant effort is being expended to argue and debate benefits of a regulatory effort using irrigation efficiency.

EFFECTS OF INCREASED EFFICIENCY

In many parts of the Sacramento Valley, water is diverted from the natural stream course and is used by multiple entities through reuse prior to being returned to a natural stream course and eventually flowing to the Sacramento-San Joaquin Delta. For example, in the Colusa Sub-Basin of the Sacramento Valley, water that is diverted by Sacramento River Settlement Contractors from the Sacramento River is initially used within their respective service areas and drains to the Colusa Drain. It is then rediverted by numerous individuals and other entities, including Sacramento River Settlement Contractors and other contractors, for reuse within their service areas prior to eventually being returned to the Sacramento River at the Knights Landing Outfall Gates. This Sub-Basin, from the uppermost point to the Knights Landing Outfall Gates, is approximately 80 miles in length. It is bounded on the east by the Sacramento River, on the west by the coastal mountains, on the north by Stony Creek, and continues southerly and terminates at the confluence of the Colusa Drain and the Sacramento River. A portion of the Colusa Sub-Basin is to the south and west of this confluence, but represents a very small portion of the overall sub-basin. By taking the microscopic view of irrigation efficiency at the turnout level, field level, or even at the district level; we as water managers may miss the important fact that the historical development of this agricultural land has resulted in an overall high efficiency of water use at the sub-basin level. If we evaluate the percentage of the quantity of water consumed to the quantity of water diverted for the sub-basin; both surface and ground water, we find percentages in the mid-90's. Within the Colusa Sub-Basin, if the upstream districts became more efficient by reducing tailwater, water supplies would not be available for the lower end of the Colusa Sub-Basin that have been relied upon for many years. This would possibly lead to three possible actions for or by the water users in the lower end of the Colusa Sub-Basin. These three outcomes are: 1. pursue alternative surface water supplies, 2. pursue groundwater supplies, or 3. reduce irrigated land. Therefore, regulating water diversions through irrigation efficiency in one area would potentially cause inadvertent adverse impacts in other areas. Irrigation efficiency must relate to the physical water system and not to a particular turnout.

In 1997, Kenneth H. Solomon and C.M. Burt authored a paper titled, "Irrigation Sagacity: A Measure of Prudent Water Use". Webster's dictionary defines sagacity as: keen in sense of perception. The parameter irrigation sagacity was proposed by Solomon (1993) to quantify both reasonable and beneficial uses of water. This parameter would classify those other uses that through the classic definition of irrigation efficiency would likely be assumed or perceived to be inefficient, as reasonable and prudent uses of water. For this reason, I believe the use of irrigation sagacity is more appropriately tied to California's system of water rights, which is based on reasonable and beneficial use.

In order to evaluate the potential opportunity for improved water management, possibly through turnout level measurement, and to consider a form of irrigation sagacity, we again have chosen the Colusa Sub-Basin to provide some estimates to evaluate this potential. Using the Department of Water Resources land use surveys, there are approximately 615,000 acres of agricultural land within this sub-basin. Of these 615,000 acres, approximately 210,000 acres are in rice production. The approximate average surface water diversions during the April through October period for 1998 through 2002 were 1.2 million acre-feet. It is important to understand this does not include any estimate for groundwater use within the sub-basin. The groundwater use has been estimated in the range of 400,000 acre-feet, based on the Sacramento River Settlement Contractors' Basin-Wide Water Management Plan, currently in an administrative draft review process with the Bureau of Reclamation. Outflow from this sub-basin occurs at the Knights Landing Outfall Gates to the Sacramento River and through the Knights Landing Ridge Cut, which flows to the Yolo Bypass channels. The outflow at the Ridge Cut is minimal due to agricultural users taking advantage of this water supply in lieu of Sacramento River diversions or groundwater diversions. Therefore, the outflow through the Knights Landing Outfall Gates is a reasonable estimate of the total outflow for the entire sub-basin. The April through October average outflow for the period 1998 through 2002 was approximately 200,000 acre-feet, or 17% of the total surface water diversions, again not including groundwater diversions. An assumption we have made is that all water use within the sub-basin is reasonable, beneficial, and prudent, and have not made any further evaluation of this relative to use within the sub-basin. Besides the crop consumptive use, the other consumptive uses are for riparian vegetation which provides habitat for various species. We would find it difficult to reduce the water use associated with this habitat in light of various environmental requirements. Deep percolation that occurs is to a useable groundwater basin, and considering the required irrigation technique for rice, this is reasonable. Even other crops require some level of deep percolation in order to fully irrigate the crop.

We want to evaluate that portion of the outflow that could possibly be retained and reused to a greater extent, in order to reduce diversions and improve irrigation sagacity. A portion of the 200,000 acre-feet of outflow occurs during August and September when the standing water in rice fields is drained in order to facilitate harvest of the rice crop. Based on the monthly quantities of outflow occurring in August and September, when the rice crop is being prepared for harvest; and based on an assumed depth of water over the 210,000 acres of rice, we estimate 75,000 acre-feet of water is flowing out of the sub-basin as a result of this cultural practice for rice. It is our understanding this cultural practice for rice production is required and therefore, would be considered reasonable and prudent. In evaluating the outflow records, it is clear there is a level of flow within the Colusa Drain that occurs naturally. We estimate this natural flow is approximately 75,000 acre-feet. The remaining outflow from the sub-basin that could possibly be recaptured for reuse is 50,000 acre-feet, which represents 4.2% of the 1.2 million acre-feet of surface water diversions. This represents the potentially available water to meet the goals of the various regulatory agencies in improved water management through increased level of turnout level measurement. If we extrapolate the 50,000 acre-feet over five months of May through September, the result is an average of 170 cfs. This 170 cfs represents approximately 2% of the Sacramento River flow during that time period. I question the ability to measure this small percentage of flow and the cost associated with the potential benefit of recapturing this water for use.

TRANSFERS AND EFFICIENCY

In the past, there has been conflict in the effort to promote transfers through increased efficiency within the Sacramento Valley. There are perceptions that water made available through increased efficiency is automatically available for transfer and therefore, the feasibility of water conservation projects should be evaluated through a cost-benefit analysis assuming the saved water is transferable. A major portion of conserved water in the Sacramento Valley results in rerouted flows, and not a total reduction of consumptive use. This form of water conservation is not transferable on a short term basis due to the protections to address potential injury to junior downstream water right holders, including the CVP and SWP. The quantity of reduced diversions as a result of water conservation efforts is possibly transferable, but likely not on a one-for-one basis. The potential ability or opportunity to transfer conserved water should not be used to require conservation efforts by the water right holder.

It is interesting to note the current draft water transfer guidelines being used by regulatory agencies include some discrepancies between crop idling, which is considered a water conservation effort, and groundwater exchange transfers. Crop idling transfers only allow for the reduction of crop consumptive use as the transferable quantity, and do not account for any reduction of deep percolation to the groundwater basin. The argument is that this reduction of deep percolation should not be transferable because it is going to a usable groundwater basin that is relied upon by a down gradient groundwater user. However, that same entity can pump groundwater to meet its irrigation requirement and offset its surface diversion on a one-for-one basis for transfer purposes. This lack of clarity in the water transfer guidelines causes Sacramento Valley water users concern due to the apparent conflict in the regulatory guidelines.

CONCLUSIONS

Agricultural water users within the Sacramento Valley are coming under more and more pressure to increase irrigation efficiency on a geographical boundary that may result in inadvertent and adverse impacts to the historically developed system of agricultural water use. Whether these pressures are real or perceived, existing water code sections provide the tools for water right holders to document and protect the valuable water supplies and rights that they have developed over many years. There will be continued pressures through water transfer proposals which will clarify the transferability of conserved water, in addition to the crop consumptive use savings. It is critical for us, as the technical representatives, to provide clear and accurate estimates or representations of the benefits and impacts of efficiency and the transferability of water made available through improved efficiency. The water management practices that have developed over many years within various sub-basins of the Sacramento Valley show a high level of reasonable and beneficial use. We should step back and consider whether our current processes and regulations are focusing on the area of losses and greatest benefit for meeting our goals through water use efficiency. If increasing irrigation efficiency at a small geographical boundary is for public perception benefit only, then it is our job to identify the potential adverse impacts of viewing and possibly regulating water use on a small geographical boundary. In addition, we should identify the existing level of efficiency at a larger geographical boundary in order to provide a clear balanced view of potential benefits and impacts.

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THE ROLE OF WATER TRANSFERS IN THE FUTURE TRANSFORMATION OF CALIFORNIA'S CENTRAL VALLEY

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ABSTRACT

We examine the motivation, rationale, and experience gained from a proposed transfer of water from an agricultural water district in California's San Joaquin Valley to another agricultural district on California's central coast. We describe how the idea for the transfer was generated, how discussions with landowners were conducted, and how the transfer has been structured to minimize potentially negative impacts on the area of origin. The transfer we examine involves the Broadview Water District and the Pajaro Valley Water Management Agency. Broadview landowners have been motivated to sell their land and water by rising costs and uncertainty, caused in part by reductions in water deliveries from the U.S. Bureau of Reclamation and increases in environmental regulations pertaining to agricultural activities. The Pajaro Valley Water Management Agency wishes to increase its supply of surface water and to reduce its reliance on groundwater in areas where overdrafted aquifers are threatened by seawater intrusion. The proposed transfer of water from Broadview to Pajaro has attracted substantial attention in California because irrigated farming likely will be discontinued in Broadview when the transfer is completed. Similar transfers might occur throughout a substantial portion of the San Joaquin Valley during this century.

INTRODUCTION

We describe a voluntary water transfer being implemented in California's San Joaquin Valley, in response to environmental objectives regarding water supply and water quality. Irrigation water supplies to agricultural districts in a portion of the Valley have been reduced in recent years by new laws and operational decisions designed to improve wildlife habitat. At the same time, water quality criteria for the San Joaquin River have been tightened to reduce ambient concentrations of salt, boron, and selenium. Farmers have been encouraged to improve water management practices and to retire some lands from production, to reduce the volume of drainage water entering the River. Much of the drainage water contains salt, boron, and selenium.

California water quality authorities have been working since the mid-1980s to reduce the volume of agricultural drainage water entering the San Joaquin River. Some of the programs implemented to enhance water quality have required

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farmers to improve irrigation and drainage practices, leading to higher fixed and variable costs of production. In addition, several irrigation districts have had to re-use drainage water to reduce effluent volumes, causing substantial increases in the salinity of water deliveries. Re-use of drainage water will cause soil salinity to increase, over time, particularly if leaching opportunities are limited by restrictions on the disposal of saline drainage water.

Federal legislation also has placed upward pressure on agricultural production costs in recent years. The Central Valley Project Improvement Act (CVPIA) of 1992 reallocated a large portion of federal water deliveries in California from agricultural to environmental uses (Weinberg, 1997, 2002). Farm-level water supplies have been reduced and the average fixed cost of water delivered to farms has increased. Water supplies have been reduced also by recent applications of the Endangered Species Act (ESA) of 1973. Water project operations have been modified to achieve flow and temperature criteria designed to protect aquatic species, resulting in smaller water deliveries to agricultural users.

The combined impacts of the CVPIA, the ESA, and new water quality regulations have been sharpest on water districts located south of the Delta formed by the convergence of the Sacramento and San Joaquin Rivers. Pumping stations that lift water from the Delta for delivery to those districts must be operated to minimize harm to fish in the Delta. As a result, annual water deliveries to some districts have been reduced to 60% of the volumes specified in contracts that were signed originally in the 1950s and 1960s. In addition, some districts have been required to reduce their discharge of saline drainage water to the San Joaquin River by more than 30% since 1996, and further reductions will be required through 2010 (Oppenheimer and Grober, 2003). These changes in water supply and water quality policies have reduced farm-level expectations regarding net revenues in a large portion of the San Joaquin Valley.

Landowners in the Broadview Water District have acted on those lowered expectations by jointly seeking a buyer for their land within the District. The Pajaro Valley Water Management Agency responded to a Request for Proposals distributed by the landowners in 1999. The Pajaro Agency subsequently has entered into sales agreements with all landowners in Broadview. The Agency wishes to re-assign Broadview's water supply contract to its service area on California's central coast, where farmers produce strawberries, vegetables, and other highly valued crops.

We describe the Broadview-to-Pajaro transaction from the perspectives of both the buyer and the sellers. Landowners in Broadview seek to sell their land at a price that is enhanced by the value of their water supply contract. Pajaro seeks to obtain a surface water supply that will enable it to reduce groundwater pumping in a region threatened by seawater intrusion.

THE PROPOSED BROADVIEW-TO-PAJARO TRANSACTION

Several characteristics of the proposed land sale and water transfer from Broadview to Pajaro motivate our analysis:

1. The proposed transfer involves two agricultural water districts.

2. The water will be obtained by purchasing all of the land in Broadview and re-assigning the District's water supply contract to the Pajaro Valley Water Management Agency.

3. The Pajaro Agency has negotiated individual purchase and sales agreements with all landowners in Broadview.

4. Irrigated agriculture largely will be discontinued in Broadview after the water is transferred because the District does not have an alternative source of water.

5. The issues motivating landowners in Broadview to sell their land are similar to issues facing many farmers in California's San Joaquin Valley.

We begin by describing the issues motivating landowners in Broadview to seek a buyer for their land and water. We describe also the issues that have motivated Pajaro to search for additional water supplies and to consider purchasing land and water from a district in the San Joaquin Valley, at a distance of 144 km from its service area. We then describe the potential gains to Broadview landowners and to farmers in Pajaro.

Broadview Seeks a Buyer for Its Land and Water

The 3,700-ha Broadview Water District is located on the west side of the San Joaquin Valley of California, approximately 80 km west of Fresno. The District was formed in the 1950s so that farmers could obtain a water supply contract from the U.S. Bureau of Reclamation. Farmers in the area had been using groundwater for many years, but the salinity of the groundwater had increased to levels unsuitable for crop production. Surface water stored in Lake Shasta in northern California is delivered to Broadview and other districts in the region via the Sacramento River and the Delta-Mendota Canal.

Major crops in Broadview include cotton, tomatoes for processing, cantaloupes, and seed alfalfa. In a typical year with a full water supply, farmers plant about 1,800 ha of cotton, 400 ha of tomatoes, 320 ha of cantaloupes, 280 ha of seed alfalfa, and 900 ha of other crops. Some land is left fallow when the annual water supply is not sufficient to irrigate all land in the District. Prior to 1990, land was fallowed for that reason only once, in 1977, when drought conditions resulted in a

75% reduction in the District's water supply. By comparison, land fallowing was required in three consecutive years in the 1990s, due to water supply reductions caused by drought conditions and by public policies enacted to protect endangered species (Loomis, 1994; Wichelns *et al.*, 2002).

Crop yields in Broadview have been higher than the average yields reported for Fresno County in most years since the District obtained its drainage water outlet in 1983. However, since 1998, the yields of cotton and tomatoes have declined with respect to the average yields reported for Fresno County (Wichelns *et al.*, 2002). The causes of this apparent shift in productivity might include increasing soil salinity in the District, due to persistent recycling of saline drainage water in recent years. That strategy has been made necessary by reductions in surface water deliveries and restrictions on the volume of drainage water that can be discharged from the District. The prospect of continuing difficulties regarding water supply and drainage management has contributed to the desire of many landowners in the District to sell their land.

In November 1999, the landowners in Broadview jointly distributed a Request for Proposals to purchase all farmland in the District. The announcement was motivated by several considerations:

1. The District had been approached by a consortium of individuals expressing an interest in purchasing lands within Broadview to gain access to the District's water supply contract.

2. Negotiations with that consortium ended without a successful sales agreement.

3. The District was considering major upgrades in its water delivery and drainage systems that would have required substantial long-term financing and repayment.

4. Several landowners in the District expressed interest in selling their land, if an appropriate transaction could be arranged.

The landowners issued the Request for Proposals to determine if a willing buyer was available, before moving forward with major upgrades of the District's facilities. A time dimension was described in the Request, so the District could proceed with its investment program in a timely fashion if a willing and qualified buyer was not available.

The desire among landowners to sell their land in Broadview and terminate their farming or leasing operations developed over many years. Since the 1980s, landowners and their tenant farmers in Broadview have been required to address several challenging issues regarding drainage water management and water supply. The adjustments made by the District and farmers to address those issues have raised the cost of farming. In addition, the reliability of the District's water supply has been reduced by changes in water supply policies required by the Central Valley Project Improvement Act of 1992 and by recent implementation of several provisions of the Endangered Species Act of 1973. Those changes and new restrictions on the volume of drainage water that can be discharged from districts in the San Joaquin Valley have reduced the probability that irrigated agriculture will remain viable in the region.

Issues regarding the discharge of saline drainage water arose in the mid-1980s, when elevated concentrations of selenium at the Kesterson National Wildlife Refuge were attributed to agricultural drainage water that had been used there as a source of water supply (Letey *et al.*, 1986; California, 1987; National Research Council, 1989; Posnikoff and Knapp, 1997). Subsurface drainage systems are installed beneath 3,035 ha in Broadview and, since 1983, most of the drain water has been discharged into ditches that carry commingled surface and subsurface drainage water from several irrigation and drainage districts into the San Joaquin River. The subsurface drain water contains boron and selenium that are leached from soils when excessive irrigation water is applied.

Broadview began implementing economic incentive programs in 1989 to motivate farm-level improvements in water management practices that would reduce the volume of subsurface drain water generated in the District. Those programs have included increasing block-rate prices for irrigation water, farm-level allotments of the District's annual water supply, low-interest loans for investments in gated pipe and sprinkler irrigation systems, and restrictions on the discharge of surface runoff (Wichelns and Cone, 1992a, 1992b; Wichelns *et al.*, 1996a). The programs largely have been successful in motivating farmers to improve water management, resulting in smaller water deliveries per unit area and smaller volumes of surface runoff and subsurface drain water.

Implementing some of the programs has raised the average cost of farming, as farmers have hired additional irrigators and invested in gated pipe and sprinkler systems (Wichelns *et al.*, 1996b, 1997). Drainage service fees also have increased to pay for participation in a regional program in which drainage water from several districts is collected, transported, and discharged into a stream that enters the San Joaquin River. Water costs have increased also, particularly in years when water supplies to irrigation districts in the San Joaquin Valley are reduced due to drought conditions or to policies that require changes in the operation of water project facilities. The U.S. Bureau of Reclamation charges a higher per-unit cost of water in years when deliveries are reduced. In addition, some farmers purchase water in market transactions at relatively high prices in years when supplies are not adequate to satisfy irrigation requirements.

The persistent reductions in annual water deliveries and the outlook for continuing pressure on water supplies in California have added substantial uncertainty to near-term and long-term perspectives regarding the viability of agricultural production. Broadview farmers expect to receive, on average, only 60% of their annual contract supply of 8,843 m^3 per ha. That amount, 5,306 m^3 per ha, is not sufficient to maintain production on all land in the District every year, while also leaching salts from the soil profile in some years. As a result, farmers must leave some land fallow, resulting in a higher average cost of farming, as taxes and assessments must be paid on all of their land.

The future cost of addressing drainage issues also is uncertain. Broadview has implemented new management strategies for many years, but the loads of salt and selenium in subsurface drainage systems remain larger than the District will be allowed to discharge in future. California's Central Valley Regional Water Quality Control Board is preparing new rules that will require further reductions in the salt and selenium loads reaching the San Joaquin River (Oppenheimer and Grober, 2003). Districts will be required to implement more aggressive monitoring programs to generate better information regarding the source and movement of those constituents in watersheds (Quinn and Karkoski, 1998). It is not yet clear that farmers will be able to sustain the higher costs required to implement new programs and comply with tighter restrictions on discharges.

Pajaro Valley Seeks Additional Water

The Pajaro Valley Water Management Agency is a state-chartered local agency responsible for managing groundwater resources in the Pajaro Valley of California (USBR, 2003). There are about 80,000 residents in the Valley, which is located on the Pacific coast, just north of Monterey and about 160 km south of San Francisco. Agriculture is the major economic activity and primary crops include strawberries, raspberries, vegetables, and tree fruit. The yields and revenues obtained from these crops in the Pajaro Valley are substantially larger than yields obtained in other areas. Farmers generate aggregate revenue of about \$500 million per year from 12,141 ha of high-valued crops, resulting in average revenue of more than \$40,000 per ha (McNiesh and Wichelns, 2004). Agricultural land values and the average value of irrigation water are substantially higher than in most other regions. Annual leases for agricultural land exceed \$5,000 per ha in some areas of the Pajaro Valley (USBR, 2003), while agricultural leases in the San Joaquin Valley generally are less than \$500 per ha for field crops including cotton, tomatoes, and winter forage (Campbell-Mathews *et al.*, 1999; May *et al.*, 2001; Valencia *et al.*, 2002; Hutmacher *et al.*, 2003).

The service area of the Pajaro Agency includes 197,000 ha of irrigated agricultural lands, native and non-irrigated lands, the City of Watsonville, and unincorporated urban communities. Groundwater is the primary source of water for both municipal and agricultural users. Groundwater withdrawals have exceeded annual recharge for many years in the region, resulting in a perpetual overdraft of the basin. The consequent reduction in groundwater elevation has allowed seawater from the Pacific Ocean to move into the coastal aquifer, degrading groundwater quality. Elevated levels of chloride in agricultural wells, caused by seawater intrusion, can damage crops when the water is used for irrigation (USBR, 2003).

The Pajaro Agency was formed in 1984 for the purpose of developing a management plan for groundwater resources. The current rate of withdrawal is viewed as unsustainable, given the problem with seawater intrusion. Pajaro has examined several plans for reducing withdrawals and establishing sustainable water management in the Valley. The recommended plan includes enhancing water conservation activities, reducing withdrawals, banking groundwater outside the Pajaro Valley basin, and importing surface water that currently is delivered to agricultural districts in the San Joaquin Valley (PVWMA, 2002).

Many irrigation districts in the San Joaquin Valley have contracts with the U.S. Bureau of Reclamation for the annual delivery of surface water from the federal Central Valley Project (CVP). Pajaro can obtain the right to transfer water from a CVP irrigation district in the San Joaquin Valley using one of two approaches:

1. Purchasing the right to transfer a CVP water supply contract assignment from an irrigation district.

2. Purchasing all of the land in an irrigation district and re-assigning the water supply contract to lands within the Pajaro service area.

Pajaro can implement either of these approaches, in part, because the Agency is a member of the CVP, although it has not obtained a CVP water supply contract of its own. The likelihood that Pajaro will receive a contract for new water deliveries from the CVP is small, because the Bureau of Reclamation must achieve certain requirements identified in the Central Valley Project Improvement Act before it may generate any new, long-term contracts for water supply (Weinberg, 1997, 2002). However, the CVP is authorized to deliver water to lands within the Pajaro service area if the water is transferred from an existing water service contract.

In 1999, Pajaro acquired 7,725,000 m^3 of annual CVP contract supply by purchasing the right to re-assign the water delivery contract of the Mercy Springs Water District in northern Fresno County, California. The re-assignment of the Mercy Springs contract to lands in the Pajaro Valley is subject to the same environmental restrictions that limit the volume of water delivered annually from the CVP to districts located south of the Delta. Hence, Pajaro expects to receive only 60% of the annual contract volume in most years (USBR, 2003).

Pajaro plans to purchase all of the land in Broadview, which also is located in Fresno County, and re-assign Broadview's contract to lands within the Pajaro service area. Pajaro began negotiating with individual landowners in Broadview in 2001, and the Agency is planning to close escrow on the agreements it has obtained in 2004 (ESA, 2004). When the land sale is completed, Pajaro will serve as the Board of Directors of Broadview and it will have the authority to re-assign water deliveries from lands within Broadview to lands in the Pajaro service area.

Pajaro can implement a voluntary transfer of water from the San Joaquin Valley to the Pajaro Valley either by purchasing the right to assign a water delivery contract or purchasing all land in an irrigation district. The sale of the right to assign a contract must be approved by a district's Board of Directors, which represents landowners and water users. The sale of land is a private landowner decision, in which the district does not have a direct role. When all of the land is sold, the new owner can determine where the water will be delivered. The new owner also can choose to sell or lease a portion of its water supply in years when it does not require the full amount of water involved in the transfer agreement

The Pajaro Agency cannot begin receiving surface water deliveries until it constructs conveyance facilities that are needed to transport water from the CVP system to its service area. A large pipeline will be constructed to accommodate CVP water deliveries made available by the purchase of land in both the Mercy Springs and Broadview Water Districts. The estimated cost of the pipeline is $130 million and the expected completion date is 2007 (USBR, 2003).

The Potential Gains to Participants

The primary motivation for Broadview landowners in jointly seeking a buyer is to sell their land and re-invest the revenue in a different activity. That goal is consistent with the recommendation embodied in the fundamental arbitrage equation. An optimal investment strategy requires that the opportunity cost of holding an asset must be offset by the sum of capital gains and annual dividends, adjusted for the value of any physical depreciation. If the sum of those components falls below the opportunity cost, the owner should sell the asset and invest in another activity with the same level of risk. The decision to sell their land suggests that Broadview landowners have determined that their opportunity cost is greater than the sum of the annual rental payments they receive from tenants and any capital gains, adjusted for depreciation.

The total value of the proposed land sale in Broadview is $25 million, or about $6,800 per ha. That price can be viewed as a point estimate of the value of the farmland asset. Current rental rates for irrigated farmland in the San Joaquin Valley range from $300 to $430 per ha (Campbell-Mathews *et al.*, 1999; May *et al.*, 2001; Valencia *et al.*, 2002; Hutmacher *et al.*, 2003). Those rates represent annual dividends ranging from 4.4% to 6.3%, given the asset value of $6,800 per ha. Those proportions compare favorably with the current yield on U.S. Treasury 10-year notes (4.18%) and the average national rate of return on 5-year certificates of deposits (3.55%), which are relatively risk-free investments (Wall Street Journal, 2004). If owning farmland and leasing it to tenants also were risk-free activities, then Broadview farmers should retain their land, particularly if they expect any capital gains and if they expect no physical depreciation.

Broadview landowners might expect the annual return on their land to be smaller than their opportunity cost because: 1) The annual rental rates for farmland (annual dividends) will be reduced in years when a full water supply is not available, 2) Uncertainty regarding future changes in water policies can reduce or eliminate capital gains, and 3) Persistent re-use of saline drainage water can cause soil salinity to increase and soil productivity to decline (physical depreciation). Given these possibilities, the Broadview landowners can gain financially by accepting the offer of $6,800 per ha and investing the revenue in an alternative activity. Broadview landowners also will achieve the goal of discontinuing their involvement with water supply and drainage issues in the San Joaquin Valley, at least with respect to their ownership of land in Broadview.

Farmers in the Pajaro Valley will gain greater assurance regarding the volume and quality of their future water supply. The farm-level cost of water will increase in the Pajaro service area to pay for new facilities needed to import surface water. However, there is no alternative plan that will enable Pajaro to stabilize the groundwater elevation and prevent further intrusion of seawater, while maintaining all of its agricultural production. The Agency has determined that it must disallow groundwater pumping in the coastal portion of its service area to stabilize the aquifer. Surface water imports will enable farmers in Pajaro to continue producing high-valued small fruits and vegetables, although the cost of production will increase with higher prices for irrigation water.

The average cost of pumping groundwater in Pajaro Valley is $75 per 1000 m^3. The Pajaro Agency charges farmers a groundwater augmentation fee of an additional $65 per 1000 m^3. Hence, the total cost of groundwater is $140 per 1000 m^3 (USBR, 2003). That cost is higher than the cost paid by most farmers in the San Joaquin Valley, where surface water prices range from $25 to $160 per 1000 m^3, but most farmers obtain water for less than $70 per 1000 m^3 (Valencia *et al.*, 2002). However, the value of crops is much higher in the Pajaro Valley and the cost of water represents a small portion of production costs and revenues. The estimated annual cost of producing strawberries is more than $70,000 per ha, while the estimated returns are more than $80,000 per ha (USBR, 2003). The estimated annual cost of applying 8,000 m^3 of groundwater on strawberries in Pajaro Valley is $1,120 per ha, or about 1.6% of total production costs.

The estimated increases in the groundwater augmentation charge and the price of surface water in the Pajaro Valley are $63 and $159 per 1000 m^3, respectively

(USBR, 2003). Annual production costs for typical crop rotations will increase by less than 1% for farmers using groundwater and by about 2% for farmers using surface water. Net revenue will decline by less than 6% for farmers using groundwater and by about 14% for farmers using surface water. These estimates can be viewed as upper bounds of the actual impacts of higher water prices, given that farmers likely will improve water management practices and implement other changes in their production methods in response to the higher input prices.

CONCLUSIONS

The voluntary sale of land and water from landowners in the Broadview Water District to the Pajaro Valley Water Management Agency will generate benefits for the sellers and the buyer. Broadview's water contract will be re-assigned from a region in which salinity and drainage problems threaten the viability of irrigated agriculture, in part, because return flows degrade water quality in the San Joaquin River. Farmers in the Pajaro Valley produce high-valued strawberries, tree fruits, and vegetables. The incremental value of the water once delivered to Broadview water will increase when the transfer is implemented. At the same time, the volume of subsurface drainage water generated on the west side of the San Joaquin Valley will be reduced when Broadview lands are no longer irrigated.

The potential economic impacts on farm supply industries and local communities are beyond the scope of this paper, but they deserve consideration in a broader analysis of issues pertaining to changes in policies regarding water supply and water quality. That analysis would be helpful in demonstrating the inevitable tradeoffs that must be considered when choosing public policies and in identifying measures to mitigate any potentially harmful indirect impacts of voluntary water transfers.

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DESALTING — PAST, PRESENT AND FUTURE

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ABSTRACT

Research in desalting technology has been ongoing for decades. There will be an increasing need for desalting, both brackish water and sea water, in the near future. The Office of Saline Water conducted a substantial desalting research program in the 1950s through the 1970s at various locations in the United States-Roswell, NM; Wrightsville Beach, NC; San Diego, CA; Freeport, TX and Webster, SD. Researchers were also actively involved in the development of desalting facilities in Israel and Saudi Arabia. Other facilities were being constructed in Key West, FL and Guantanamo Bay, Cuba.

The desalting research was instrumental in resolving the salinity issue with Mexico on the lower Colorado River. In 1961 when the drainage channel was completed from the Wellton-Mohawk Irrigation District in Arizona to the Colorado River, the water quality in the river degraded substantially, resulting in Mexico registering concern to the United States. After substantial study the solution was authorized in the Colorado River Basin Salinity Control Act of 1974. The primary activity in the lower basin was the construction of the Yuma Desalting Plant and the construction of a drainage channel extension. Since that construction was completed, a number of issues have arisen regarding the operation of the desalting plant. Desalination has a future in the world not only for improvement of water quality but also as a supplemental water supply.

INTRODUCTION

Desalination is a relatively recent scientific method for the treatment of brackish and sea water. Although primitive methods of simple distillation have been in use for centuries, it was not until the early 1950's that a significant research effort was undertaken. In 1952, the Saline Water Research Act was passed by Congress (Act of July 3, 1952, 66 Stat. 328). The Congress, at that time, recognized that the availability of fresh water supplies is limited and that other means would be needed to ensure that domestic water would continue to be available for the future. In that regard, Congress made the following policy statement when it passed the Act: "In view of the increasing shortage of usable surface and ground water in many parts of the Nation and the importance of finding new sources of supply to meet its present and future water needs, it is the policy of the Congress to provide for the development of practicable low-cost means for the large-scale

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production of water of a quality suitable for municipal, industrial, agricultural, related thereto. As used in this Act, the term "saline water" includes sea water, brackish water, and other beneficial consumptive uses from saline water, and for studies and research and other mineralized or chemically charged water."

The Office of Saline Water was established in 1955 in the Department of the Interior to conduct the research authorized by the Act of July 3, 1952.

Even though the Congress recognized that research was needed in the field of desalination, it was aware that specific results were not possible under the provisions of existing legislation. Therefore, in 1958, the Congress passed a bill (Act of September 2, 1958, Public Law 85-883, 72 Stat. 1706), providing for the construction, operation, and maintenance of not less than five demonstration plants for the production, from sea water or brackish water, of water suitable for agricultural, industrial, municipal, and other beneficial consumptive uses. The plants would be designed to demonstrate the reliability, engineering, operating, and economic potentials of the sea or brackish water conversion processes. Congress directed that each plant would demonstrate a different process.

For the above purposes, a demonstration plant meant a plant of sufficient size and capacity to establish on a day-to-day operating basis the optimum attainable reliability, engineering, operating, and economic potential of the particular sea water conversion process or the brackish water treatment process.

In accordance with the direction of Congress the Office of Saline Water established five demonstration sites across the United States in areas, types, and capacities cited in the Act.

At Wrightsville Beach, NC, the process known as freezing was researched and demonstrated for sea water. At Roswell, NM, vertical tube evaporators were investigated for conversion of brackish water. At San Diego, CA, a multi-stage flash distillation plant was developed to remove salt from sea water. The electrodialysis method of treating brackish water was demonstrated at Webster, SD. Sea water was converted by electodialysis at Freeport, TX. Even though vapor-compression distillation was initially investigated at Roswell, eventually the Brackish Water Test Center was added to demonstrate reverse osmosis.

The Office of Saline Water conducted research and demonstrated the processes at these sites until the office was reorganized with the Office of Water Resources Research into the Office of Water Research and Technology in 1974. After that, funding of research by the Federal Government declined substantially. Ongoing research was conducted on a smaller scale by the Bureau of Reclamation, Department of the Interior, until the Salinity Control Act was enacted in 1974

As a result of this and other research around the world a number of operating desalination plants of various sizes were constructed. The various methods varied by the type of water to be treated, the amount of energy needed for the process, the availability of heat and or energy, and the capacity required.

Plants of various sizes were constructed in the United States, Saudi Arabia, Israel and Guantanamo Bay, Cuba, with the advice and assistance of researchers from the Office of Saline Water.

After some experiences with the different types of treatment most potential users looked more favorably on reverse osmosis as the method of choice. Consequently, this paper will focus on the reverse osmosis process.

REVERSE OSMOSIS

Reverse osmosis is a method for removing salts from water by applying pressure to the brine, forcing the water through a semi-permeable membrane which leaves the salts behind and collecting the purified water on the other side of the membrane. Reverse osmosis is capable or treating feed waters of up to 45,000 mg/L total dissolved solids. Most reverse osmosis applications involve brackish feed waters ranging from about 1,000mg/L to 10,000 mg/L.

As referenced earlier, the reverse osmosis process was researched and demonstrated at the Office of Saline Water's facility at Roswell, NM. The Bureau of Reclamation also funded several test modules of different processes, including reverse osmosis, at various sites in the Western United States. Other plants have been built at Key West, San Diego, Tampa, and the Los Angeles area for a supplemental water supply. A larger scale reverse osmosis plant was constructed for the Orange County Water District.

The world's largest reverse osmosis desalination facility planned in the U.S. was authorized by Congress in 1974 as a part of the Colorado River Basin Salinity Control Program (Act of June 24, 1974, P.L. 93-320, 88 Stat. 266). It is referred to as the Yuma Desalting Plant.

A test facility was established near Yuma, AZ, in the early 1970's, to evaluate membrane configurations and to develop design data for pretreatment processes and membranes, ultimately to be used for the Yuma Desalting Plant.

YUMA DESALTING PLANT

The history of the Yuma Desalting Plant begins in 1961 when pumped drainage water flowing into the Colorado River from the Wellton-Mohawk Irrigation and Drainage District resulted in elevated salinity levels in water delivered to the Republic of Mexico.

Water deliveries for use by irrigation and municipal entities on the lower Colorado River in Arizona and California are diverted at imperial Dam. The Gila Project, Arizona, diverts Colorado River water on the east side of Imperial Dam into the Gila Gravity Main Canal. Colorado River water is then transported to the Gila Project irrigation districts, including the Wellton-Mohawk Irrigation and Drainage District. District facilities were completed in the early 1950s. However, irrigation had been practiced in the Wellton-Mohawk area since the 1500s with more intensive irrigation in the late 1800s and the early 1900s. The water source initially was the Gila River and when drought conditions persisted wells were drilled for irrigation purposes. Even then salinity was an issue because of the continuous recycling of the water. Therefore, in the late 1950s, a decision was made to drill a large number of drainage wells to reduce the groundwater table to control the salinity levels. Drainage water was collected and carried to the Colorado River through the Wellton-Mohawk Main Conveyance Channel which entered the river at its confluence with the Gila River. In accordance with the Treaty of 1944, Mexico is entitled to 1.5 million acre feet of water annually from the Colorado River. Mexico's diversion is located at Morelos Dam near Yuma, Arizona, at the Northerly International Boundary between the United States and Mexico. This diversion is a number of miles downstream of Imperial Dam and several miles below the point where drainage water from Wellton-Mohawk enters the Colorado River which results in increased salinity in the water diverted by Mexico.

The Drainage Channel was completed in 1961 and almost immediately Mexico objected to the increased salinity. Although the Treaty was silent on water quality, the United States started investigations in late 1961 to alleviate the problem. The early solution was to extend the drainage facilities and bypass the drainage flows around Morelos Dam. But this solution resulted in water being delivered to Mexico in excess of the Treaty requirements and caused concern in the seven Colorado River Basin states in the United States that the excess water would be accounted for as water used in the U.S. In essence, these excess deliveries come out of storage in the reservoirs which, in the long term, would have a deleterious effect on future diversions particularly in the event of long term drought..

The concerns of the seven basin states led to the appointment of Herbert Brownell by President Nixon in 1972 to determine a permanent and definitive solution to the salinity issue. Mr. Brownell established a task force composed of various Federal and State agencies and representatives of the seven basin states. Mr. Brownell's task force, supported technically by primarily the Bureau of Reclamation, met over a period of several months. The task force studied a number of alternatives and ultimately recommended a desalination plant to be constructed just upstream of Morelos Dam. The intent of the plant was and is to treat the Wellton-Mohawk drainage water to a more suitable water quality for release in the Colorado River above Morelos Dam.

Mr. Brownell's recommendations, while favored by some agencies and the basin states, were not universally accepted. The main objections centered on the high capital costs and the very high operating costs of the desalination plant. However, Mr. Brownell prevailed and his recommendations were accepted by President Nixon and the Mexican Government. The decision was memorialized by Minute 242 to the Treaty of 1944, which also set water quality requirements at the Northerly International Boundary with Mexico.

The Colorado River Basin Salinity Control Act (Public Law 93-320) was enacted by the Congress to implement the recommendations of the Brownell task force. The Act authorized the construction of the desalination plant and several other facilities. The Act also authorized the construction of a drainage channel extension (50 miles long) to the above mentioned drainage channel, to convey the Wellton-Mohawk drainage water into Mexico and deposited in the Santa Clara Slough, a low-lying area near the Gulf of California. The extension of the drainage channel was intended to be a temporary solution while the desalination plant was being constructed.

The extension of the drainage channel was constructed in the U.S. by the U.S. and the portion in Mexico was constructed by Mexico. It was completed in 1977.

Construction of the desalination plant was started in 1980. The plant, considered the world's largest reverse osmosis membrane desalination facility, will treat a portion of the Wellton-Mohawk drainage water then blend with the remaining drainage water to meet the water quality requirements of Minute 242. The original capacity of the plant was 129 million gallons per day but was later modified to about 78 million gallons per day because of the reduction of the amount of drainage water by implementing certain activities at the Wellton-Mohawk District.

The membranes are fabricated by two manufacturers and were installed in the late 1980s. Significant pretreatment facilities are required because of the quality of the incoming drainage water. The plant was substantially completed in 1991 and was operated at one-third capacity in 1992 for about six months. In that there was surplus water in the Colorado River at that time, the plant ceased operations. Since 1992, the plant has been undergoing continuous review, updating, and correction of design deficiencies. It is estimated that the plant will be ready to operate in 2006.

More recently, the Bureau of Reclamation started a readiness assessment in 2002 for a complete and current review of the requirements for startup and operations of the Yuma Desalting Plant.

The assessment objectives were to update the understanding of expected costs, to develop present costs on a delivered price basis for product water, and to provide a means to update costs as conditions change in the future. Some of the key findings include: additional front end costs of $26 million will be needed to restart the plant; after restart, operating costs are estimated to be $24-28 million per year for full plant operations; and the estimated cost for product water is $300-800 per acre foot depending on certain conditions.

The issue of plant restarting is critical to the Colorado River basin states and particularly to the lower basin and the State of Arizona. With the drought in its fifth year or longer depending on who is providing the timeframe, the operation of the plant would save a substantial amount of water currently going unused into Mexico through the drainage channel. While this water is now too saline to use for almost any purpose, desalting that water would permit the treated water to be available for use in the U.S. or for use in meeting Mexico's treaty entitlement. Restarting the plant is an issue from an environmental standpoint as the Santa Clara Slough has become a wildlife habitat.

The Yuma Desalting Plant has the potential to be a major factor in ensuring maximum possible use of water in the lower Colorado River. It was designed to meet that objective and there are many interests working to see that it does.

FUTURE OF DESALTING

The history, objectives, status, and potential of the Yuma Desalting Plant indicate how desalination of both brackish and sea water can be utilized for meeting water needs in the future, not only for water quality but also for water supply.

Some areas of the world, such Saudi Arabia and other desert areas may have absolutely no alternative except desalination. Others will use the process to improve water quality for industrial processes, as a supplemental supply, or to just improve water quality such as taste improvement.

As population increases and water supplies become more strained water laws will be challenged to provide mechanisms for the use of desalted water in exchanges. For example, some inland areas may share a river water supply with a coastal city. If the inland area has a deficiency of water, it may have an option of constructing a desalination plant to desalt sea water to supply the coastal city in exchange for the coastal city not taking an equivalent amount of its entitlement from the river. Several coastal cities now have active plans to construct desalination plants for sea water conversion to supply increasing needs because no other alternative is available.

Desalination, as has been discussed above, is not a new technology, but the high costs have been a deterrent to its selection as a water source or water treatment. With desalination becoming more common as time goes on costs will be more competitive and this option will be more attractive.

ESTIMATING ACTUAL EVAPOTRANSPIRATION WITHOUT LAND USE CLASSIFICATION

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ABSTRACT

Water resource planning requires knowledge of consumptive water use by crops and natural vegetation. Remote sensing offers the promise of obtaining consumptive use and other water resource data over large areas at regular intervals. SEBAL (Surface Energy Balance Algorithm for Land) uses data gathered by satellite-based sensors to compute the energy balance at the earth's surface. Evapotranspiration (ET) is predicted as a residual of the energy balance, without needing to know crop or vegetation type, or other ground-based information, except routine weather data.

Utilizing SEBAL, annual *actual* ET in 2002 for the state of California has been computed from *MODerate-resolution Imaging Spectroradiometer* (MODIS) satellite images for each square kilometer. Annual ET can be summarized spatially using any spatial characteristic for which a GIS overlay is available or can be developed. Annual ET was summarized spatially by land use, county and watersheds. Validation of the SEBAL process is discussed in general and for this specific application. Annual a*ctual* ET from a MODIS pixel comprised of largely alfalfa fields was found to differ by 0.9 percent from alfalfa annual actual ET measured by a lysimeter maintained by the United States Department of Agriculture, Agriculture Research Service near Fresno, California (Ayars and Soppe, 2003).

INTRODUCTION

Water resource planning requires knowledge of consumptive water use by crops and natural vegetation. The accepted approach to determining consumptive use of

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water by crops and natural vegetation begins with computation of a reference ET using data from nearby weather stations (Jensen, et.al. 1990 and Allen, et.al. 1998). Many computation methods exist for reference ET. However, in the last few years the Penman-Monteith combination equation has gained wide acceptance. Differences in reference ET between locations account for most of the climatic differences between areas. The next step is to select and apply crop coefficients for individual crops and natural vegetation types. The crop coefficients selected must have been developed for use with the selected method for computing reference ET. Crop coefficients are by definition (Allen, et.al. 1998) developed for standard (sometimes called "pristine") conditions. Standard conditions are defined as "disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions." Thus, consumptive use or ET computed in this manner is standard, or "pristine," ET.

Actual ET can be obtained from "pristine" ET in a variety of ways. A simple technique is to discount actual ET by a percentage, such as 7% (Cal Poly, 2001), to account for low crop density, poor fertility conditions, high salinity and other factors that occur in production agriculture and tend to suppress ET. Other more intensive methods include a root zone water balance coupled with water application amounts and dates to estimate soil water stress and ET reduction experienced by crops.

Computation of "pristine" ET requires detailed weather data and crop type and area information. When accurate weather and crop type and area information are available, accurate values are obtained for "pristine" ET. For well managed irrigated areas with sufficient water availability, these values in aggregate are reasonably accurate and can be considered representative of actual ET with a small percentage reduction (Burt, et.al. 2002). However, ET for each crop is considered uniform within and among fields. For water-short or salinity-affected irrigated areas, determination of actual ET becomes much more difficult because these influences tend to be spatially variable.

Remote sensing offers the promise of determining irrigated area and crop ET for large areas with spatial sensitivity. ET can be computed as the residual of the surface energy balance without the need for crop type information and irrigated area is integral to the process. ET computed from the energy balance is the actual ET, as compared to the "pristine ET," and is the total ET of precipitation and applied water.

This paper provides a brief overview of remote sensing and data products derived from remote sensing, presents results from the application of remote sensing to compute ET at a large spatial scale (1 km by 1 km square pixels) for the state of California in the year 2002, and finally compares the results to other ET measurements.

PART 1. OVERVIEW OF REMOTE SENSING ET PRODUCTS

Remote Sensing

Remote sensing can be defined as the collection of information about an object from a distance. In this paper, remote sensing generally refers to measurement of spectral radiances sensed by satellites or airplanes. Remote sensing from aircraft can be flown whenever desired and is generally of higher resolution. However, satellite images (remotely sensed data) are more readily available.

Most satellite remote sensing relies on naturally reflected or emitted radiation from the earth's surface. The imaging systems are designed to take images of visible, near infrared, thermal and microwave energy. Thus, a single satellite "image" is comprised of many (seven in the case of Landsat-7) separate images, or bands, each corresponding to a different wavelength. Image analysis is accomplished by treating each band as a raster layer in GIS. This paper focuses on remote sensing from satellites.

Remote Sensing Applications

A wide variety of individual parameters have been mapped from remote sensing data utilizing many different technical solutions. Some of these individual parameters include: vegetation indices to determine the extent and health of vegetation, thematic classification into crop types, irrigated area and land cover and use (Bastiaanssen, 1998). Other biophysical crop parameters that can be computed from remote sensing measurements include: fractional vegetation cover, leaf area index, photosynthetically active radiation, surface roughness, broadband surface albedo, thermal infrared surface emissivity, surface temperature, surface resistance, crop coefficients, transpiration coefficients, ET and crop yield. Additional information that can be derived from remote sensing includes: soil moisture, soil salinity and soil mineralogy. Remotely sensed ET at sub-field resolution across a large region contributes significantly to improving water resources management. Schultz and Engman (2000) provide a recent overview.

Remotely sensed ET at sub-field resolution across a large region contributes significantly to improving water resources management. Kustas, et. al. (2003) describe two modeling schemes to compute ET from data remotely sensed by the Geosynchronous Operational Environmental Satellite (GOES). A major disadvantage of these two approaches for agricultural applications is the large pixel size of 5 to 10 km^2. ET cannot be evaluated at the sub-field or even field scale due to the coarseness of the spatial resolution. Moreover, these technologies do not provide an accumulated value for ET. SEBAL (Surface Energy Balance Algorithm for Land) combines satellite remote sensed data with weather station data, to solve the energy balance at the earth's surface for the actual ET and biomass production of agricultural crops and native vegetation. Actual ET can be obtained at field and sub-field scale and for seasonal accumulated values. Since SEBAL computes the energy balance on the basis of spectral radiances, information on crop development is not required. As discussed in Part 3 of this paper, the finer spatial resolution of the SEBAL results enables validation comparisons against lysimeters in many instances. Bastiaanssen et. al. (2004) provides a detailed description of the SEBAL algorithm.

PART 2. CALIFORNIA 2002 ET, BIOMASS PRODUCTION AND WATER USE EFFICIENCY

One MODIS image covering California was processed with the SEBAL algorithm to compute actual ET and biomass production on a scale of 1 km by 1 km for each month of 2002. The processing was completed without land use classification. The CIMIS network of automatic weather stations was used in conjunction with the DAYMET high-resolution climate grid to fill out the days between consecutive MODIS images (Thornton et al., 1997).

The result of this processing was an actual ET value for each square kilometer pixel in California for each month, in the form of an ArcInfo Grid, or raster, coverage. This raster coverage can be converted to 409,616 polygons, each with an area of one square km and a unique computed value of actual ET. The result is 12 of these raster coverages, one for each month in 2002. In GIS, this information can be overlaid with other spatial coverages for analysis. The remainder of this paper provides just a few examples of the analytical possibilities.

The actual ET values for California are at the lower end of the SEBAL accuracy spectrum due primarily to the use of a single image per month and lack of adjustment for surface roughness. The lack of adjustment for the surface roughness results in inaccuracies, particularly for the forest ecosystems. A single surface roughness, selected for greatest accuracy in the agricultural areas, was used in the SEBAL computations. The small differences in surface roughness among agricultural crops allow for the use of a single surface roughness for these areas and ET to be computed without specific crop information. The larger surface roughness difference between agricultural areas and mature forests results in over estimation of ET for the mature forests. A similar over estimation occurs for the bare rock/desert areas. Higher accuracy in the ET estimates could be achieved by processing additional images and by applying appropriate, spatially sensitive refinements to surface roughness.

ET by Land Use

A 1992 statewide land use map was obtained (USGS, 2003) and superimposed on the ET grids from 2002. The USGS National Land Cover Characterization team made this high-resolution 30 m land use database. The 21 land use classes have been consolidated to reduce the number of classes to 12.

The land use areas that consumed the most water in 2002 in terms of depth of ET were the forest ecosystems and open water (Table 1). The lack of a 2002 land use map introduces some uncertainty in the results. Nevertheless, the potential of evaluating the ET rates and volumes for each land use class is demonstrated. Wetlands followed by orchards/vineyards and agricultural crops come after the forest ecosystems. Built up ("urban") areas consumed only slightly less than agricultural crops. Not surprisingly, bare rock and desert consumed the least amount of water.

Table 1. Annual 2002 ET by Land Use Class in California (1 km^2 resolution)

Land Use	Area, ac	Total, in	Volume, AF	area,%	Volume,%
Mixed forest	3,323,164	54.4	15,065,012	3.3%	5.4%
Open water	1,127,315	53.5	5,025,947	1.1%	1.8%
Deciduous forest	1,888,596	49.7	7,821,936	1.9%	2.8%
Evergreen forest	22,720,724	49.4	93,533,647	22.4%	33.6%
Wetlands	385,449	43.4	1,394,041	0.4%	0.5%
Orchards/Vineyards	2,656,290	41.2	9,119,928	2.6%	3.3%
Agricultural Crops	9,224,304	37.2	28,595,341	9.1%	10.3%
Built-up area	3,017,239	35.5	8,925,997	3.0%	3.2%
Grassland/Herbaceous	15,071,265	33.3	41,822,761	14.9%	15.0%
Perennial ice/snow	9,810	32.3	26,405	0.0%	0.0%
Shrubland	35,641,046	21.1	62,668,840	35.2%	22.5%
Bare rock/desert	6,153,055	9.3	4,768,618	6.1%	1.7%
Totals	101,218,258	33.0	278,768,475	100.0%	100.0%

Figure 1 shows the monthly distribution of ET during 2002 for five of the land use classes. As expected, ET from wetlands is roughly the same as for open water in March and April, however beginning in May the wetland ET begins to be less than the ET of the open water surface, presumably due to insufficient water supplies to support full wetland ET. The agricultural area appears higher than expected in March. The built-up area ET appears lower than expected in May and higher than expected in November. These may be due to climatic or management effects.

ET by County

Figure 2 shows that 40 percent of California counties had an average actual ET of 40 inches or greater. Conversely, 10 percent had an average actual ET of less than 26 inches. (Note: averages are not weighted by county area.)

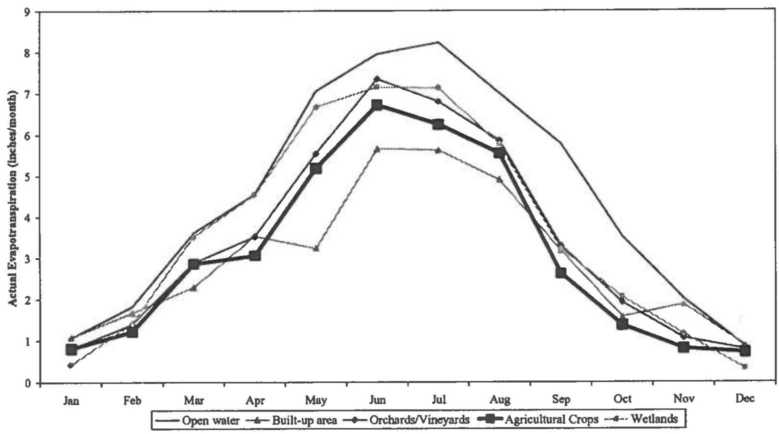

Figure 1. Monthly ET in 2002 computed from MODIS satellite images.

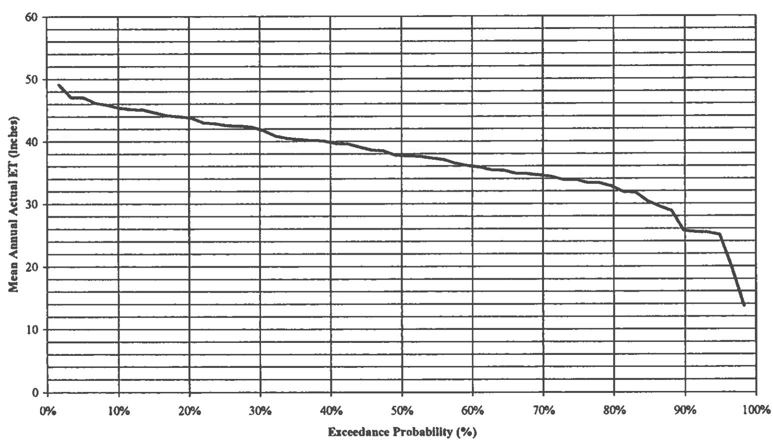

Figure 2. Mean California County 2002 Annual Actual ET Exceedance Probability

Actual ET and biomass production (another SEBAL output) were combined to compute water use efficiency. WUE is defined as the biomass production in dry mass per area divided by the actual ET. It should be emphasized that this is the efficiency per unit of water depleted, i.e. water that has evaporated into the atmosphere and is no longer available for downstream users. Table 2 lists the top five counties in California in 2002 in WUE. Sonoma County ranks number one in terms of water use efficiency in 2002. This county ranks 14th in biomass production, but only 43rd in actual ET. The county has a significant area in wine grapes and it is likely that the regulated deficit irrigation practiced is a leading factor in the high water use efficiency. The county with the highest annual actual ET, Humboldt county, is ranked fifth in WUE, while Mendocino county has the highest biomass production and is ranked second. As expected, all of the counties in the top five have significant forested area.

Table 2. Top Five California Counties in 2002 in Water Use Efficiency (WUE)

No.	County	Biomass, tons/ac	Actual ET, inches	WUE, lbs/acre-inch of ET
1	Sonoma County	11.1	33.9	655
2	Mendocino County	14.1	43.8	644
3	Santa Cruz County	11.9	38.5	618
4	Del Norte County	12.2	43	567
5	Humboldt County	13.8	49.1	562

ET by Watershed

The California Department of Water Resources (CDWR) has divided California into ten major Hydrologic Regions corresponding to the State's major drainage basins, or watersheds, for the development of the California Water Plan (CDWR, 1998). By overlaying the GIS polygons for these watersheds, the mean actual total ET for 2002 of all the 1 km^2 pixels in each of these watersheds is computed (Table 3). (Here too, annual ET is the total ET of precipitation and irrigation combined.) The land use polygons can now be overlaid on the watersheds and the actual annual ET in each watershed broken down by land use area.

Table 3. Mean Annual Actual ET in 2002 for California's Ten Major Watersheds

No.	Watershed	Area, acres	Mean Annual Actual ET, inches	No. of Sub-watersheds
1	North Coast	12,442,916	42.7	1566
2	San Joaquin	9,800,815	41.1	769
3	Sacramento River	17,409,785	40.3	1454
4	South Coast	7,149,255	38.2	345
5	Central Coast	7,370,731	35.9	842
6	Tulare Lake	10,767,959	35.7	754
7	San Francisco Bay	2,892,803	35.1	274
8	North Lahontan	3,909,887	33.9	354
9	Colorado River	12,711,832	19.2	63
10	South Lahontan	17,572,920	16.3	601

PART 3. COMPARISONS TO OTHER ET ESTIMATES

Comparing ET computed by SEBAL to that determined by other ET estimating techniques presents difficulties in both the temporal and spatial dimensions. Table 4 lists some of the most common ET measurement technologies along with the temporal and spatial scales associated with them.

Table 4. ET Estimating Techniques by Temporal and Spatial Scales

	Scales	
ET Estimating Techniques	Temporal	Spatial
SEBAL	Instantaneous*	0.2 to 250 acres
Lysimeters	Hourly	10-20 sq. ft.
Eddy Correlation	Instantaneous	20-40 acres
Bowen Ratio	Instantaneous	20-40 acres
Scintillometer	Instantaneous	1000 to 2000 acres
Water Balance	Monthly	Thousands of acres

*SEBAL estimates actual ET flux at the moment of satellite image capture. The instantaneous flux can be reliably extrapolated to hourly, daily and longer periods.

Many consider good lysimeter data sets to be the best standard for ET measurements. However, many researchers have indicated the difficulty of maintaining proper lysimeter conditions. One of the challenges is keeping the vegetation within the lysimeter representative of the surrounding field. This is obviously critical for comparisons against SEBAL considering the spatial scales of the two technologies. In a comparison of SEBAL results to lysimeter measurements in the Bear River Basin in Idaho (Allen, et. al. 2002), for July through October for grass, the seasonal ET computed by SEBAL was 4.3% greater than that measured by the lysimeters (15.9 compared to 15.4 inches).

Additional SEBAL validation comparisons across many climates and ET measurement technologies are described in Bastiaanssen, et. al. (2004). These comparisons have indicated that for short-time periods based on a single satellite image, SEBAL results are within 15 to 20 percent of other measurements. For longer time periods, based on a multiple satellite images, up to and beyond a full season, random errors inherent in a process that includes semi-empirical relations cancel. Thus, SEBAL results are typically within five percent of other reliable ET estimates for seasonal and longer periods.

<u>California 2002 Annual ET Comparison to Lysimeter Data</u>

The USDA (Ayars and Soppe, 2003) measured the ET of alfalfa throughout 2002 using a weighing lysimeter in the vicinity of Parlier. The "West" lysimeter was maintained under farmer management conditions, while the "East" lysimeter was maintained under optimal agronomic conditions. Thus, the ET measured by the

East lysimeter is considered to be near potential while that from the "West" lysimeter more closely represents actual ET under commercial farming conditions. The "West" lysimeter field was located on a Landsat image and found to be a few pixels in size and in an area dominated by grapes. Thus, the corresponding MODIS pixel could not be used because the pixel including the "West" lysimeter was mostly grapes and the actual ET for this pixel would be essentially a weighted average of the grape area and the alfalfa area. This obstacle was overcome by using several large fields, recognized as alfalfa fields by their spectral pattern, for the comparison. A MODIS pixel from this area was selected for comparison with the "West" lysimeter data. The actual ET by SEBAL for the satellite image days compares well to the curve of lysimeter-measured crop ET (Figure 3). The difference in the annual crop ET between the lysimeter (45.9 inches) and SEBAL (46.4 inches) is 0.9%.

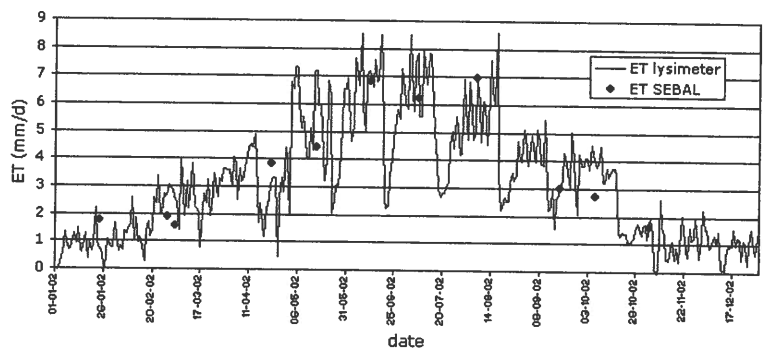

Figure 3. Comparison of Alfalfa ET to lysimeter ET (Ayars and Soppe, 2003)

CONCLUSIONS

Spectral radiances captured by satellites enable estimation of actual ET using energy balance techniques. One of these techniques, SEBAL, is widely tested and validated. It offers the advantages of not needing to know the crop type, computing actual ET directly and providing a spatial view of ET. Once ET is computed by SEBAL and an ArcInfo Grid is generated, this information can be combined with other spatial coverages for a wide variety of hydrologic analyses.

Determining *actual* ET has always been an imposing, if not insurmountable challenge. The promise of remote sensing and estimation of *actual* ET with SEBAL is an easier, more accurate method for all those applications for which an accurate determination of *actual* ET is critical. The method opens up a new era by enabling water managers to "see" the spatial variability in *actual* ET, leading to higher levels of understanding in hydrologic processes.

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OPENBASIN — AN OPEN SOURCE SOFTWARE FRAMEWORK FOR REAL-TIME WEB-BASED HYDROLOGIC DATA DISSEMINATION

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ABSTRACT

The Open Source software movement is making waves in the computer industry. Linux, an Open Source operating system, is fueling much of the interest. The authors here describe the OpenBasin software suite which runs under Linux. This package of software is released under the same license as Linux. This means that the underlying source code is freely available and there are no licensing fees. OpenBasin builds on several years of work by a private contractor, StoneFly Technology, and employees at the U.S. Bureau of Reclamation in Provo, Utah (USBR Provo Office). This software is currently being used by several water districts in Utah, including Emery Water Conservancy District, Sevier River Water Users Association, and Weber Basin Water Conservancy District. OpenBasin allows users on the Internet access to real-time hydrologic and weather data. Water users and mangers use this data to make timely decisions regarding water deliveries. OpenBasin is in the process of being enhanced with features such as water rights modeling, evapotranspiration reports, interactive voice response (IVR), and alarming via email and phone for user defined events. The authors hope that wider use of this software will lead to enhancements and feedback from the user community.

INTRODUCTION

The task of collecting, storing, manipulating, and displaying real-time hydrological and weather data for an entire river basin is not a simple task. Creating such a system without suffering a sharp learning curve is even more complex. This is the problem that lead StoneFly Technology and personnel from the USBR Provo Area Office to develop OpenBasin. These two organizations have created and operated real-time data collection and dissemination systems for Emery Water Conservancy District, Sevier River Water Users Association, and Weber Basin Water Conservancy District for a number of years. Recently, the desire to create a standard set of software to use for this work lead to the creation of OpenBasin.

In order to create a single software solution for these widely different organizations, many factors had to be carefully considered. For instance, within each site many different data logging systems existed. Each system recorded data

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from a unique set of sensors and used a different data logging format. In addition, data had to be collected from a number of data sources; for example the US Geological Survey (USGS) and the National Weather Service (NWS). The question became how to incorporate these varied data sets into one database that would allow the user to access the most basic and most sophisticated data sets with the same amount of ease.

Apart from collecting and accessing data, data display needs for each organization differed. A uniform approach needed to be devised which would allow a high level of customization. This was accomplished by an internal templating system within OpenBasin, and generic display tools which can be customized to fit the need of any organization, including completely customizable graphing tools and dynamic data maps that display the most current data values.

A useful system required that data collection be automated. Therefore tools were designed that automatically collect data through a number of different methods and recognize many different data formats. Also, the data collection automation tool was left open for additional customization to facilitate any data collection request. Furthermore, data manipulation was taken into consideration so that the collected data could be converted, manipulated, or even used in a mathematical function with other data to create new data products.

Finally, the operation of this complex system of software utilities had to be reduced to a user-friendly format to enable the software to be easily configured by a person unfamiliar with OpenBasin's underlying software. For this reason, the OpenBasin administration tools were developed. The administration section of OpenBasin bridges the gap between the software and the users. Through this easy interface the user is able to access all of OpenBasin's functionality without the requirement of extensive computer expertise.

Implementing the web sites from Emery Water Conservancy District, Sevier River Water Users Association, and Weber Basin Water Conservancy District using OpenBasin has proved to be a great benefit for those involved. Due to the functionality built into OpenBasin, development time can be focused on adding additional features to the web sites rather than rewriting software. Furthermore, less time is involved in managing and customizing the sites as was previously required.

FEATURES

System Templating

At the heart of OpenBasin design model is the ability to easily use information from widely varied data sets. The innovative solution discovered was a technique called system templating. Through this technique, multiple levels of data access are involved. This multi-level approach allows for low levels of the program to resolve any differences between data sets, and integrate them so the user of the programmer simply uses the data as if was all the same.

Examples of this include the following situation: given two stations, one which records temperature in Celsius and one which records temperature in Fahrenheit, the database will store the information as it receives it. However, when the user requests temperatures in Fahrenheit, OpenBasin will automatically recognize that the other data is stored in Celsius and perform the automatic conversion. Thus the user does not need to worry about inconsistencies in the data.

Another example involves measuring the water level of a reservoir. Some measurement devices measure how high the water is from the reservoir floor, while others measure the difference between the current level and some arbitrarily assigned reference point. These differences can be very confusing and difficult to overcome when storing and displaying data. However, once configured, OpenBasin will automatically realize that it needs to report its data consistently between data sets, allowing seamless access to incompatible data.

Customizable Utilities

OpenBasin comes pre-bundled with a number of utilities which allow OpenBasin users to display their data in easily customizable formats. Examples of these utilities include dynamic graphs, dynamic data maps, and tabular data listings.

Dynamic Graphs: Dynamic graphs allow data to be displayed over time. Features include the ability to change the time span of data the user is viewing and the ability to compare one set of data with another. These graphs can also be configured to automatically add the option to compare all relevant data sets any time one of the data sets is displayed on the graph.

Dynamic Data Maps: Dynamic data maps are a very useful feature for displaying data in a simple format. The basic idea behind a data map is to use a graphic representing a map, and then dynamically add data points onto the map which specify the recorded data readings at those locations. These data locations are fully customizable and can be clicked on to access more detailed information.

Another useful feature included with the dynamic data maps is the ability to display teacup diagrams for reservoirs. These diagrams use the most recently recorded height to calculate what percentage of the reservoir is full of water. With this calculation, it shows both a graphical depiction of the water storage and a description detailing what percentage of the reservoir is filled with water.

Tabular Data Listings: Tabular data listings are a quick way to see the raw data for a specified amount of time in a table format. These listing are very useful for hand calculations or pattern recognition. These listings may also be converted into an exportable file.

Administration Pages

The OpenBasin Administration pages are an important part of the OpenBasin suite. Through this easy-to-use interface, nearly all common functions of OpenBasin can be configured and customized. They are the bridge that closes the gap between the software and the user. Through them the user can add, edit, or delete new stations. New data types may be defined or data collections methods can be edited through the administration pages.

Another unique feature of the administration pages is the ability to include administration features from additional packages that are compatible with OpenBasin. Even custom utilities that a user creates on their own may be integrated into the OpenBasin administration system. This feature allows all OpenBasin administration to occur from one concentrated location.

Interactive Documentation

Without adequate documentation any software package is incomplete and virtually useless. The OpenBasin website <http://www.openbasin.org/> provides instructions on how to install, activate, configure, or properly use certain features. The instructions provide a quick and easy means to accomplish a task. Also on the OpenBasin website are tutorials. Tutorials are more in depth than the instructions and attempt to explain the inner workings of OpenBasin. These tutorials help the user gain a broader overview of the entire OpenBasin software suite. They also assist in explaining harder or more complex concepts dealing with OpenBasin.

OpenBasin also includes an automatic, interactive documentation system. This documentation system is primarily used by the website developers as a reference for the many features built into OpenBasin. An added feature of this documentation system is that when enhancements, customizations, or plug-ins are added onto the OpenBasin framework, documentation concerning those additions may also be displayed on the OpenBasin interactive documentation system. In fact, OpenBasin can even automatically detect additions and add them to the documentation—even if the addition is completely designed and created by independent developers.

Finally, the interactive documentation not only allows for additions, but changes to previously installed OpenBasin components. If for any reason a user finds it necessary to change the inner-workings of OpenBasin to better their organization, the documentation can be changed to reflect these changes. Also, when new components are added, descriptions of their usage and functionality can automatically be included in the documentation. Therefore, the OpenBasin documentation can be completely customized to fit an organization's need, just as the OpenBasin software package itself can.

Automated Data Collection

Data collection with OpenBasin is fully customizable and automatic. Even though data is collected through a variety of means in a variety of formats, data collection is greatly simplified by data collection types. With data collection types, the user simply groups similar data sets together and defines a method in which the computer should recognize the data. Once this is configured properly, OpenBasin will automatically collect data for each data station according to the data collection type to which it is assigned.

With the automated data collection system, the time of data collection can be customized for each data collection type or each station. Some data is available every hour, some every 4 hours, and some every 15 minutes. OpenBasin simplifies these differences by providing data collection at any specified time, and it records in the database how recently the data was received and how often the data is available.

Automated Data Calculation

Data can also be manipulated or calculated automatically. This means that data that is collected can be used to generate other data. Useful implementations of this include automatically converting from one unit of measurement to another or calculating the reservoir capacity from the reservoir height. There are two ways to perform this task, calculation upon data collection and database-driven calculation.

Calculation upon Data Collection: The first method of automated data calculation is accomplished by performing calculations on specified data as it is collected, and then storing the results of the calculations to the database. These calculations can be anywhere from simple unit conversions to complex equations involving many data inputs. A benefit of this style of calculation automation is that it is very easy and very fast. However, if any subsequent changes are made directly to the database after the data is already collected, none of the calculated data will be altered.

Database-Driven Calculation: The second method involves storing the code to calculate the additional data directly within the database. With this system, anytime data is added to the database the additional data will be calculated and stored in the database at the same time. However, with this style of automated calculation, anytime the data is changed directly from within the database, the pre-calculated data will be recalculated and updated as well. Therefore, the integrity of calculated data is much high with this method. Unfortunately, this method of data calculation is more difficult to setup than the data collection calculation system, but work is under way to add features to the OpenBasin administration pages that will greatly reduce the difficulty of database-driven calculations.

Automated Data Integrity Checking

As described above, one way to ensure the integrity of calculated data is to use the automated database-driven calculation system. However, there are also ways to ensure the integrity of raw data. First, the OpenBasin package is carefully designed to ensure that all collected data is stored in the proper location with the proper time associated to it. Even with this careful design, due to communications or equipment failure, erroneous data may be recorded. To compensate for this fact, OpenBasin includes error-checking mechanisms such as minimum and maximum values. OpenBasin can also be configured to recognize questionable rates of change with in the past and current data. Additionally, OpenBasin can be configured to display the data as collected, ignore the data, delete the data, or notify the system administrator. This flexibility allow OpenBasin to be customized to fit the needs or any organization.

ENHANCEMENTS

In addition to the core features of the OpenBasin software suite, work has progressed on enhancements to the original OpenBasin package. These enhancements seamlessly attach onto the OpenBasin core to provide more advanced or more specialized features. These features, along with the entire software suite, are licensed under the General Public License (GPL). The GPL allows users free access to the complete source code and eliminates the possibility of licensing fees.

Water Allocation

Particularly useful for irrigation purposes, water allocation modeling assists water managers by allowing them to make more informed decisions. Using a system of models utilizing current weather information and historical data, the water allocation modeling feature in OpenBasin accepts a desired flow at numerous branches of the irrigation canal and calculates the amount of water necessary to be released into the canals.

Due to the inadequacy of a single model to accurately predict all factors influencing water allocation modeling, OpenBasin includes multiple models in order to provide a more accurate range. Since the models are fundamentally based on different input factors, anomalies in the data are less likely to have a drastic effect upon water irrigation.

OpenBasin's water allocation models give water managers data which allows them to quickly make more informed decisions.

Evapotranspiration Reporting

To calculate evapotranspiration a complex system of formulas and weather data is used. OpenBasin simplifies this task by automatically generating evapotranspiration reports based on real-time weather data. Additionally, daily and hourly evapotranspiration records are kept to further assist with irrigation uses.

Akin to evapotranspiration modeling is reservoir evaporation modeling. OpenBasin has the ability to automatically model reservoir evaporation using similar weather data. Reservoir evaporation models are useful in self-checking water balance models and other data analysis procedures.

Wireless Data Access

Interactive Voice Response (IVR): To improve the accessibility of OpenBasin-controlled data, work has been performed providing access to real-time data via a touchtone telephone by utilizing an IVR system. To utilize this system, a user calls the IVR system with a telephone and inserts a designated code. This code signifies which data the caller is interested in hearing.

The benefit of this type of approach is that callers are not required to listen to a long pre-recorded information list, but they can specify directly the information in which they are interested. Also, since the data is accessible via telephone (including cell phones), a user can check real-time data virtually anywhere, anytime without the need of a computer or Internet access.

Wireless Application Protocol (WAP): Cell phones and Personal Digital Assistants (PDAs) have increased in popularity and functionality immensely over the past few years. One relatively new feature has been the creation of web-enabled cell phones and PDAs. These devices connect wirelessly to the Internet. However, since their bandwidth and processing power is much less than a regular computer, they only recognize special websites that conform to the WAP.

The OpenBasin software suite allows for data display via WAP. This feature provides employees access to real-time data readings while working onsite via a web-enabled cell phone or PDA. This barebones display is capable of showing data, tables, and simple graphs or images. Also with the OpenBasin software, these graphs and images can be dynamically generated in order to automatically include the most recent data available.

User-Defined Alarming

In any type of automated system, unprompted communication from the computer to the system administrator is requisite to gauge system performance. One common approach to providing this communication is through the use of alarms. The concept of alarms begins with the system administrator defining a set of conditions in which an alarm is raised. Examples of such conditions include data values below or above a specified minimum or maximum, erroneously large ratios of change within the data, data statistically calculated to be incorrect, or no data collection at all.

When one of the above mentioned user-defined conditions is met, the OpenBasin system automatically raises an alarm. Based on how the system is configured, the software can react to an alarm in many different ways. For example, the alarms can be logged to a file or Internet web page that the system administrator can check at their own convenience or an email can be sent to one or many people detailing the nature of the alarm. Development is also under way to combine the IVR described above to call the system administrator and inform them of the alarm. All of these approaches or any combination of them can be used through the OpenBasin software suite.

COMMUNITY USAGE

Benefits of an Expanded User Base

Already in use for multiple organizations, the OpenBasin software package has a strong repertoire of features that can provide universal functionality to any organization; however, the benefits of an expanded user base implementing the OpenBasin software within their own organizations are almost innumerable. Benefits include improved functionality, interoperability, and improved technical assistance.

Improved Functionality: As the OpenBasin software suite is used in different organizations for varied uses, the software itself must grow to meet the needs of new, different tasks it is assigned to provide. Under such circumstances, the OpenBasin software suite will grow to meet demands placed upon it, thereby, the functionality and universality of OpenBasin's features will increase. With this increase of usefulness, all users of OpenBasin will benefit from the fruit of one another's labors.

Interoperability: With the current, ever-increasing globalization of the society in which we live, access and transportation of data to different people and organizations is an essential task to provide the appropriate level of usefulness in any software package. With increased use of OpenBasin technology, fellow users will be able to communicate and even share data, information, and additional software plug-ins which will provide additional usefulness and allow for an increased level of usefulness within the OpenBasin software.

Improved Technical Assistance: A virtual community of OpenBasin users will be the result of an increasing number of users. Within this community, discussions, tutorials, tips, and tricks will all be plentiful from other, more experienced users. Also, the increased use of the OpenBasin software suite will help developers to refine and perfect the software. And since the OpenBasin software is distributed free of charge under the GPL, new users are able to join the OpenBasin community and the receive benefits of it without any monetary investment.

Already on the OpenBasin website <http://www.openbasin.org/> a number of tutorials and plug-ins are available. Example tutorials deal with installing and configuring OpenBasin and utilizing OpenBasin's built-in administration features. Example plug-ins include a system for dynamically creating images, including graphs, and other utilities useful for web development. To further assist OpenBasin users, a mailing list has been set up which allows OpenBasin users to keep in contact with one another, and a bug tracking system has been installed to provide users a valuable channel to report errors and provide feedback to software developers.

Benefits of an Expanded Developer Base

Along with an expanded user base, an expanded developer base will propel the OpenBasin software suite and ensure that optimal improvements and rapid development are a standard within the OpenBasin community. Additionally, not only will development time decrease, but with the combined backgrounds of many developers in many different situations, more robust and universal solutions will be available for every improvement or enhancement needed for the OpenBasin software suite.

Currently there are systems set up on the OpenBasin website <http://www.openbasin.org/> which facilitate the active participation of developers all across the world. The first is a CVS system that is used to manage the OpenBasin development process and involve as many developers as wish to assist. In addition to that, a bug tracking system is being utilized so that OpenBasin users can reports errors they find with the software or request enhancements or changes to developers. Finally, an OpenBasin developer mailing list has been established to increase the level of communication between OpenBasin-contributing developers.

CONCLUSION

The authors hope that the combination of Open Source software, inexpensive computer hardware, the ubiquity of the Internet and the OpenBasin software suite will lead many organizations who had not previously considered doing so to create a real-time water measurement and display system. We believe that the Internet will play an increasingly important role in water management. We invite any interested parties to join our efforts.

IMPROVING WATER MANAGEMENT IN IRRIGATED AGRICULTURE

James E. Ayars[1]

ABSTRACT

Increasing demand for food, fiber, and clean water resulting from the increase in world population is putting significant stress on irrigated agriculture. Currently, irrigated agriculture supplies nearly 40% of the world food products and is expected to contribute more in the future with less water and the same cultivated land area. Analysis of the global water supply and existing irrigation management reveals many alternatives for irrigated agriculture to meet the production challenges with the same water supply while minimizing the environmental impact of irrigated agriculture. These alternatives include: improving existing water management practices for surface irrigation, switching to alternative irrigation systems, improved management to include fertilizer management and the use of alternative water supplies including saline drainage water and treated effluent. In addition to water application, sustaining irrigated agriculture depends on managing the salt in the soil profile and the salt load emanating from the irrigated area. This can be accomplished by improving drainage system management and changing the drainage design criteria. Data from the U.S. and Australia will be used to demonstrate the effect of changes in irrigation system management on water use efficiency and drainage system design and management on the salt load from irrigated agriculture.

INTRODUCTION

Competition for water between urban, industrial, environmental, and agricultural interests will become more intense in the future. Recent studies project that the world population will increase to 9 billion people by 2050 from a current population of approximately 6 billion (UN, 2004).This increase will bring additional demands for food, clean water for drinking, water for the environment, and production of consumer goods. Currently, irrigation uses approximately 80% of the developed water supply worldwide, and this water will be a logical source for meeting other demands associated with population growth. Irrigation currently supplies approximately 40% of the world food supply on less that 20% of the arable land and has a significant future role in meeting the projected world food demand (Postel, 1999). The impact of irrigated agriculture on the total food supply is demonstrated by the fact that irrigated agriculture in California produces 55% of all the fruits, nuts, and vegetables in the United States on 3% of the total US farmland.

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Most of the land suitable for irrigation in the United States has been developed and the lack of water supplies is now the limiting factor in continued development. The alternative to new irrigation development will be to increase yields on existing agricultural areas through improved irrigation technology, improved crops, and improving productivity of lands impacted by high water tables and salinity.

The environmental consequences of irrigation may be significant if the system is poorly designed and operated. Poor irrigation practices may result in pollution of surface water with soil sediments, pesticides, salts, fertilizers, and agro-chemicals while ground water may be contaminated with agro-chemicals, soluble fertilizers (e.g., nitrate), and salts transported by deep percolation from irrigation. There will always be some salt transport associated with irrigated agriculture resulting from the need to leach salt deposited by the irrigation water from the root zone. The impact on the environment could be lessened by improved management of irrigation and drainage systems resulting in the lowest practical levels of salt transport needed to sustain production.

Integrated management of irrigation and drainage systems will be required for irrigated agriculture to be sustainable, which will require the use of new and advanced management techniques and equipment. However, the first step prior to the adoption of new technologies or management practices is to insure that existing technology and methodology have been implemented properly and to the fullest extent possible. Improved water management should help to minimize the loss of water by evaporation, transpiration, surface runoff, and deep percolation. If existing practices are not adequate to achieve the desired conservation goals then new technology and practices will need to be adopted. This paper will highlight some existing and proposed management practices that result in improved water use efficiencies and thus increased food production with the existing water supply.

IRRIGATION WATER MANAGEMENT ALTERNATIVES

A goal of improving the irrigation and drainage water management is to improve the water use efficiency (WUE) of irrigated agriculture. Water use efficiency has been defined as "the production of marketable unit of crop yield per unit of water consumed by evapotranspiration", Jensen et al. (1990). This does not imply that the maximum yield will be obtained for a given crop. One way of achieving maximum WUE is to maintain yields while reducing the applied water. This can be done by improving the efficiency of the irrigation system or reducing the total seasonal application when the irrigation system is already being operated efficiently. Three methods that result in a reduction of applied water are regulated deficit irrigation (RDI), microirrigation, and irrigation scheduling. Each of these methods is discussed in the following paragraphs.

Regulated Deficit Irrigation

Regulated deficit irrigation has the largest potential impact on perennial crops that continue to transpire after the harvestable yield has been removed and has been applied successfully to tree crops such as pears, peaches (Mitchell et al, 1986; Chalmers et al, 1986; Chalmers et al, 1981), and plums (Johnson et al, 1994). Chalmers et al. (1986) found with Bartlett pears that there were two time periods that could be used as part of an RDI scheme. The first period occurred prior to fruit expansion and the second occurred after harvest. This resulted in significant water savings without a reduction in yield. Application of the process requires an understanding of plant physiology such that water is applied during critical growth stages that insure development of the fruit and withheld during non-critical growth stages. The non critical stages will vary depending on the fruit.

In a three year study on May harvested plum, Johnson et al. (1994) found that water could be withheld from plums after the harvest was completed and not affect yield. The plums were irrigated at 100% ET until harvest after which the stress treatments were applied. One treatment (T1) received 50% of the water applied to the control at the same frequency as the control, while the second treatment (T2) was subjected to cyclic stress that varied from year to year. The second treatment (T2) received the same amount of water as T1 in a different sequence. The imposed irrigation treatments resulted in a savings of 300 mm of water over the season compared to the control without a loss in yield or quality. A total of 889 mm of water were applied to the control treatment so the stress treatments resulted in a 33% water savings. The study was done using a low volume irrigation system having 2 emitters per tree each with a discharge rate of 19L/hr on a sandy loam soil with an underlying hard pan.

Microirrigation

One of the first suggestions for improving irrigation efficiency or water use efficiency is to change the irrigation system being used. If furrow or surface irrigation is being used, the recommendation will be to switch to either sprinkler or some form of microirrigation (drip, microsprays, bubblers). This switch makes it possible to improve the distribution of water over the field and match the application rate to the infiltration rate. These systems are also capable of automated control enabling higher frequency irrigation and a better match of supply and demand. This reduces the plant stress and also deep percolation losses if properly operated.

Studies done over a 6 year period in the San Joaquin Valley using both surface and subsurface drip demonstrate the effect of irrigation frequency, drip lateral location, and fertigation on yield and WUE. An overview of the materials and methods used in the study are provided here, and the complete details of the studies can be found in Ayars, et al. (1999).

A progression of water management and fertilization experiments was conducted at the University of California West Side Research and Extension Center using a subsurface drip irrigation system (SDI), a surface drip system (SD), and a weighing lysimeter. The cropping pattern was processing tomatoes in 1984, 1985, 1987, and 1990, cantaloupe in 1986, cotton in 1988, and sweet corn in 1989. The design was a randomized block consisting of 3 treatments with 4 replications. This was modified in 1987 with the blocks being subdivided into two sub-plots. The initial installation was completed in 1984.The plots were 91 m long and contained 10 beds spaced 1.63 m from center to center.

Filtration was by nested screen with 180 mesh being the finest. The headworks consisted of 3 sections each with a computer lysimeter feedback control backed up by a time clock, electric valve, water meter, pressure regulator, and pressure gage leading to a 7.6 cm diameter polyvinyl chloride (PVC) mainline. At each plot a 2.5 cm diameter PVC manifold was connected by a 5.1 cm diameter PVC riser assembly to the mainlines. The riser assembly and plot manifold were made portable for the surface microirrigation plots. The microirrigation laterals had in-line turbulent flow emitters with flow rates of 4 L h^{-1} spaced 0.91m apart along the lateral. The SDI laterals were in the center of the bed at a depth of 0.45 m. The surface laterals were installed after planting and removed before harvest each year. The soil is a Panoche clay loam (Typic Torriorthents).

A large weighing lysimeter was used in feedback mode to schedule irrigation automatically in the SDI and SD treatments after 1 mm of crop ET_c had measured by the lysimeter. An irrigation of 25 mm was applied to the low frequency SD after 25 mm of ET_c was measured by the lysimeter. The lysimeter was irrigated using SDI and corresponded to the high frequency irrigation treatment.

<u>Irrigation frequency:</u> In this study irrigation was initiated on the high frequency plots when approximately 1 mm of ET_c had occurred resulting in up to 8 irrigations a day. The low frequency was 25 mm applied approximately once every 3 days during the heat of the summer. In either case the soil water depletion was not nearly equal to that expected when furrow irrigating. The data in Table 1 are for a tomato crop that was fertilized solely with nitrogen at the recommended rates. There was higher evapotranspiration with the low frequency surface drip (LFSD) than with either of the high frequency treatments. The data in Table 1 show that there was not a statistical difference in the yields (Y_r), but when crop water use was considered there was a statistical difference in the WUE with the high frequency surface drip irrigation (HFSD) having a larger WUE than the LFSD.

Table 1. Water use efficiency red tomatoes grown with drip irrigation in 1984.

Irrigation Treatment	Et_c (mm)	Y_r (Mg/ha)	WUE (kg/m^3)
SDI	659	121a[a]	18a
HFSD	650	126a	19a
LFSD	690	114a	16b

[a] Columns followed by the same letter are not significantly different at the 95% confidence level, as determined by the Duncan test on separation of means. Y_r yield of large red tomatoes, Et_c crop evapotranspiration, WUE water use efficiency.

High frequency automated control of the drip system was possible because of the weighing lysimeter which would not generally be available for commercial agriculture. However, there are new control technologies that enable automated control of irrigation systems with a frequency comparable to the low frequency irrigation in this study (Charlesworth, 2000; Clark and Phene, 1992; Phene et al., 1992; Phene, 1996) A frequency of application that meets the crop water requirement once every one to three days will result in less plant stress than a system that applies water once every 2 weeks. This reduced stress will have a significant impact on yield in a water stress sensitive crop like tomato.

Fertigation: The results in Table 1 demonstrate the potential effect of irrigation frequency and meeting the crop water requirement on a nearly daily basis. Similar studies were done in 1985 and 1987 using the same scheduling methodology with fertilization treatments. These data are summarized in Table 2. In 1985 phosphorus (P) was added with the nitrogen, and in 1987 both P and potassium (K) were added with the nitrogen.

Table 2. Yield of large red tomatoes and WUE for water and fertilization treatments in 1985 and 1987.

Irrigation treatments	1985 (N+P)			1987 (N+P+K)		
	Et_c (mm)	Y_r (Mg ha^{-1})	WUE (kg m^{-3})	Et_c (mm)	Y_r (Mg ha^{-1})	WUE (kg m^{-3})
SDI	751	168a[a]	22a	708	220a	31a
HFSD	741	152b	20b	695	201b	29b
LFSD	724	130c	18c	709	187c	26c

[a] Column means followed by the same letters are not significantly different at the 95% confidence level, as determined by the Duncan test on separation of means. Y_r yield of large red tomatoes, Et_c crop evapotranspiration. WUE water use efficiency.

The data in Table 2 show a significant difference in the WUE and yield as additional fertilizer components are added to the irrigation water supply. The difference in Et_c will be in part due to seasonal variability in climate across years.

When the WUE is compared between treatments there is a steady increase as fertilizer is added. The SDI treatment is consistently the largest producer. The addition of phosphorous and potassium to the nitrogen in 1987 nearly doubled the yields from 1984 in the high frequency irrigation treatments with a nominal increase in the applied water. Similar responses were seen with cantaloupe and sweet corn.

Irrigation scheduling

Irrigation scheduling should be an important part of water management, but it is often given very little consideration. The basic concept is to determine when to irrigate and how much to irrigate. This can be done using a water balance technique that provides both answers. However, the actual crop water use needs to be calculated and the storage capacity of the soil needs to be known. Both of these can be determined. The advent of computer control of irrigation systems and the potential for feedback control of an irrigation system based on changes in measured soil water content has provided additional irrigation scheduling opportunities. In feedback control mode a threshold water content is set and the irrigation system applies a fixed water volume each time the threshold is met. This may result in a high frequency irrigation that matches the crop water use and minimizes deep percolation losses.

Crop coefficient: One problem in the water balance method is the calculation of the crop water use. This is typically done by modifying the reference evapotranspiration (ET_o) by a crop coefficient (K_c). The ET_o is available in many states from regional climate station networks. The K_c values are often difficult to find and are cumbersome to use, so there is a need to provide simplified methods to develop the coefficients and to update existing coefficients to reflect new varieties. In the past, the K_c has been developed using lysimeters to measure the crop water use as a function of plant age or development. As an alternative, Grattan et al. (1998) used the Bowen Ratio method to estimate crop water use and correlated it to canopy cover. This was done for a wide variety of vegetable crop grown in the Central Valley of California. Application of the technique only requires the grower to make a simple measurement of ground cover to estimate the crop coefficient. It has the advantage of incorporating climatic impact on plant development that might not be accounted for in a system that is simply time based.

Shallow groundwater: One component of the water balance equation is the water loss or gain from the shallow ground water. When scheduling irrigation this term is routinely set to zero, which can lead to significant over irrigation in areas with shallow ground water. Including the shallow ground water contribution to the crop water use extends the irrigation interval and reduces the total irrigation demand. Ayars and Hutmacher (1994) developed crop coefficients for cotton that accounted for crop water use from shallow ground water as a function of ground water quality and depth. Similar studies need to be done for other crops. In-situ use of ground water in the range of 15 to 60% of the crop water requirement has been documented for alfalfa, cotton, peaches, pears, string bean, sugar cane, corn, and tomato. By managing this resource the WUE will also be improved because less water will be used for production.

DRAINAGE WATER MANAGEMENT ALTERNATIVES

Drainage water comes from two sources in irrigated agriculture: from surface runoff occurring naturally as part of surface irrigation, or from subsurface drains installed to control waterlogging. Surface drainage often contains silt, sediment, and a minimal amount of salt and chemicals adsorbed to the soil. It generally is suitable for reuse on an adjoining field after the sediment is removed. The subsurface drainage water will often contain salt and fertilizer. The concentration of salt will depend on the existing soil salinity levels and the depth of placement of the drains. In the past, subsurface drainage was discharged to surface water bodies without regard to the environmental consequences of this procedure. However, unregulated release of subsurface drainage and disposal of saline drainage water are major problems confronting irrigated agriculture. Several alternatives are being evaluated to solve this problem. Reuse of drainage water to supplement irrigation water supplies has been investigated (Ayars et al, 1993; Rhoades et al, 1989; Rhoades, 1989) and found to be a part of the solution. The suitability of this water for reuse depends on the crop salt tolerance, and the salinity of the water. Reuse of drainage water should be one of the last steps in the disposal process because of the potential negative impacts on the soil environment with the accumulation of salt and toxic elements. The first step should be reduction of the total drainage water volume (source control) which will minimize the volume of water requiring disposal. This was the recommendation of the San Joaquin Valley Drainage Program study (1990). This means that the irrigation efficiency should be improved to the maximum extent possible prior to implementing any drainage water reuse programs.

In addition to improving irrigation efficiency, steps should be taken to actively manage the subsurface drainage system. This is a significant departure from current practice. In the past, drainage systems were designed to draw the water table down to at least 1.2 m below the soil surface at the mid-point between the drains and to run continuously. This can result in over-drainage of the soil (Doering et al. 1982) and significant load of salt being discharged. Christen and Ayars (2001) developed a set of best management practices for the design and operation of subsurface drainage systems. They recommended initially improving the irrigation system efficiency and then installing control structures on the outlet of the drainage system. These structures maintain the water level at a fixed depth below the ground surface, prevent excess drainage, and insure that water is available for in-situ use by crops.

Outlet controls: Controlling the water table at the outlet not only maintains the water table closer to the surface but it modifies the flow path to the drains. Wider drain spacings have deeper flow paths, and in areas where salt concentrations increase with depth more salt will be discharged to the surface. When controls are placed on these systems the flow path depth is reduced and less salt is discharged. In a study in Australia, Christen and Skehan (2001) demonstrated the impact of managing subsurface drainage on salt load. The study evaluated the salt discharge from an area with deep drains (2.1 m deep), deep drains with an outlet control, and shallow drains (0.9 m deep). The results are given in Table 3.

Table 3. Salt load from subsurface drainage systems.

Treatment	Drainage Depth (mm/ha)	Average Salinity (dS/m)	Salt Load (kg/ha)
Unmanaged deep drains	70	11	5867
Managed deep drains	47	7 - 8	2978
Shallow drains	15	1 - 3	319

These data demonstrate how the electrical conductivity (EC) of the drainage water was reduced by managing the drains to create a water table depth of 1.2 m at the outlet. A further reduction in EC was achieved by using shallow drains. Controlling the drains also significantly reduced the total discharge as did using shallow drain placement. The combination of reduced flow and reduced EC resulted in significant reductions in salt load. Depending on the configuration of the drainage system, alternative designs can be developed to control individual laterals or parts of the entire system (Ayars, 1996).

CONCLUSION

There exists an extensive body of knowledge on how to manage on-farm irrigation and district operations and the challenge for the future is to implement this knowledge. The water management challenge in the 21st century will be to shift from a technology based to an information intensive system (Postel, 1999) that implements intensive management of irrigation systems. The goal will be to improve water use efficiency and get more crop for drop of water. This paper described alternatives for improved management of pressurized irrigation systems that will improve water use efficiency. The need for integrated management of irrigation and drainage was also discussed and areas for future research to improve water management in irrigated agriculture were also highlighted. There will be consequences on a watershed level associated with improved on-farm water management that will have to be considered. Less surface runoff and deep percolation from inefficient irrigation might affect the return flow to the river and impact the downstream water supply later in the irrigation season. There is no simple answer as to the total water savings that will result from the implementation of any of these practices.

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BENEFICIAL USES OF TREATED DRAINAGE WATER

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ABSTRACT

The United States Bureau of Reclamation has a legal requirement to provide drainage services to the San Luis Unit of the Central Valley Project (CVP) in Southern California. A number of options are being investigated by Reclamation, but the current favored option includes a number of approaches to water reduction and treatment, including a spiral reverse osmosis plant. A different membrane system to recover higher proportions of saline drainage water, containing saturated levels of calcium sulfate, was tested in early 2004 at a drainage collection point in Panoche Water District. Results from that work suggest it may be possible to recover over 90% of saline drainage water for unrestricted reuse as fresh irrigation water at a cost less than or equal to the cost of producing sea water by reverse osmosis. If the equivalent amount of CVP water could be sold to urban areas at a price close to the cost of treating Sea Water by Reverse Osmosis this approach could provide an environmentally friendly and negligible cost solution to the problem of drainage water in the San Luis Unit.

The Drainage Problem in the San Luis Unit of the Central Valley

The disposal of irrigation water in the San Luis Unit of the federal Central Valley Project in California has been a problem from the inception of water deliveries by the United States Bureau of Reclamation (Reclamation) in the 1960's. The San Luis Unit encompasses 700,000 acres of prime farmland in the San Joaquin Valley. In about one half this area, the local geology includes a low permeability clay lined bowl under the fields that restricts drainage into the deep water table Consequently, over 300,000 acres of irrigated lands within the San Luis Unit have had to contend with rising water levels under the productive farmland over the last 40 years. In many places, saline water is now threatening the root zone area of the crops.

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It was originally intended that Reclamation would fulfill its contractual obligation to provide drainage service to both the northern Grassland section and the southern Tulare Lake Basin section of the San Luis Unit by constructing and operating a 250-mile master drain that would empty into the San Francisco Bay-Delta. This facility, called the San Luis Drain, was partially constructed in the 1970's and began transferring agricultural drainwater from Tulare Lake Basin north to Kesterson Reservoir in Merced County. The completion of the drain to the Bay-Delta was halted, and is now generally regarded as environmentally infeasible, after the selenium in the drainwater was attributed to adverse wildlife impacts at Kesterson Reservoir in the early 1980's.

Since 1995, certain drainage-impaired lands in the Grassland Area in the northern portion of the San Luis Unit have been permitted to dispose of their drainage water under an agreement with federal and state agencies and other interested parties. Under this interim arrangement, which expires at the end of 2009, drainage water from the 97,000 acres Grassland Drainage Area is discharged into a part of the San Luis Drain and then transferred to the San Joaquin River via a 7-mile natural channel which passes through Kesterson National Wildlife Refuge. This agreement requires a year by year reduction to the amount of selenium discharged into the San Joaquin River. By 2010, the Grassland Area dischargers must have in place an alternative discharge or an alternative method for eliminating their drainage flows.

No drainage outlet has been provided to the 200,000 acres of drainage-impaired farmland in the Tulare Lake Basin section of the San Luis Unit since closure of the San Luis Drain in 1986. Maintaining the arability of this drainage-impaired land is becoming increasingly problematic each year with some land already retired as unsuitable for agricultural production.

Salts are brought into the area by irrigation water supplied from the Delta-Mendota Canal and the California Aqueduct segment of the Central Valley Project, and sulfate salts, boron and selenium are leached from the soil. With boron and salt levels too high for many crops grown in the area, reuse of the water is restricted. The high selenium level in the drainwater presents environmental challenges for the use of evaporation ponds. Projected drainage water quality ranges are presented in **Table 1** below.

Since implementation of the Grassland Bypass Project in 1995, Panoche Drainage District, and other water/drainage districts in the Grasslands Area in the northern section of the San Luis Unit, have undertaken measures to improve water use efficiency at both the farm and district level, and have implemented drainwater recycling to the extent practical in order to meet their interim selenium reduction targets under the Grassland Bypass Project. In addition, Panoche is developing a regional drainwater re-use project on behalf of all the lands within the Grassland Drainage Area in which untreated drainwater is used to irrigate salt tolerant crops on dedicated fields. These measures have reduced by approximately 50% the amount of drainage water and salts that needs to be drained from the area, but the problem is not fully resolved through these practices.

Table 1. Projected Drainwater Flows and Quality from the Northern and Southern Areas of the San Luis Unit before reduction/reuse[i]

Year	Drainage Volume (AF)	TDS Mg/l	Selenium mg/l	Boron mg/l
Northern Area SLU				
1	10.6 – 17.8	6,549 – 3,929	0.16 – 0.1	12.82 – 7.69
50	10.6 – 17.8	3,600 – 2,160	0.09 – 0.05	7.05 – 4.23
Southern Area, Zones A, B and C				
1	1.9 - 3.15	20,250 – 11,250	0.37 – 0.03	12.6 – 7.56
50	67.5 – 82.5	4,860 – 1,620	0.09 – 0.01	3.02 – 1.81

In response to a 2001 court order, Reclamation is currently evaluating alternatives for providing drainage service to its San Luis Unit water contractors. These options include reexamining completion of the San Luis Drain to the San Francisco Bay-Delta . A Pacific Ocean Discharge option was recently abandoned as being too expensive and environmentally infeasible. Land Retirement is also being considered for some of the farmland with high soil salinity levels in the southern Tulare Lake Basin Area.

As of mid 2004, the drainage service option that Reclamation considers to be most feasible is termed "In Valley Disposal". This option can be summarized by using a variety of on-farm, in-district, and regional drainwater volume reduction strategies, including the use of membrane processes for water recovery, to address the three key contaminants in the drainwater; salt, Boron and Selenium. The level of calcium sulfate in the drainage water is at or near saturation levels creating more challenges for membrane water-recovery processes. Reclamation's preliminary capital cost estimate for building the facilities necessary for implementing the In-Valley Disposal Option for all 260,000 acres in the San Luis Unit requiring drainage service is over $700 million[ii], for 100 AF drainage flows.

Cross Flow Membrane Technology for drainage water treatment

Reverse Osmosis technology uses a very "tight" semi-permeable membrane through which, in an ideal case, only water will pass, provided that the pressure exerted on one side of the membrane exceeds the natural osmotic pressure of the fluid itself. The technology is applied frequently for the treatment of saline waters. Reverse Osmosis membranes have the ability to retain dissolved salts and other solutes, while allowing water to pass through the semi-permeable membrane layer. Clearly the higher the level of salts in the fluid the higher the natural osmotic pressure and hence the higher the pressure that needs to be applied to the "raw water" side of the membrane before non-saline filtrate or "permeate" can pass thorough the membrane. Equation 1 below gives the filtration rate per unit membrane area through the membrane, J, in terms of π_0, the natural osmotic pressure of the fluid, π, the pressure applied across the membrane and k, an empirical constant derived from membrane performance.

$$J = k(\pi - \pi_0) \qquad \text{(Equation 1)}$$

For a typical reverse osmosis membrane, the concentration of sodium chloride salt seen on the permeate side of the membrane will be less than 1% of the concentration seen on the "feed" side of the membrane, giving the membrane a "retention" > 99% NaCl.

Nanofiltration technology uses similar membrane materials, but by making the semi-permeable membrane more open, allows a greater passage of salts. Further, the driving force or pressure required to pass filtrate through the membrane is lower. Nanofiltration membranes allow the majority of monovalent salts to pass through the membrane while retaining the larger proportion of the divalent salts. The energy required for nanofiltration is lower because the membrane area is smaller and/or the applied pressure is lower. The filtrate, however, will contain a higher proportion of salts than water that has passed through an RO membrane. In cross-flow membrane filtration there is a continual flow of the feed fluid at pressure across the membrane surface, while the permeate passes through the membrane at 90° to the feed's direction of flow. Cross flow filtration reduces the concentration of the retained fractions at the membrane surface through disturbance of the fluid at and near the membrane surface. If particulates are present in the feed material, these particulates will also be kept moving across the membrane surface instead of blocking the filter area. (Figure 1)

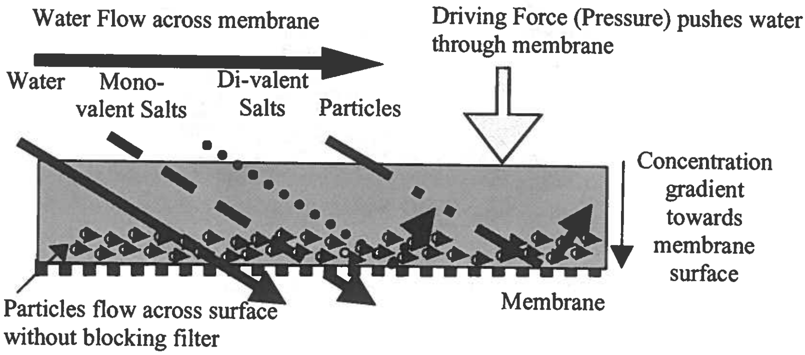

Figure 1. Cross Flow Nanofiltration Separation

Cross flow membranes can be configured in a number of ways, but for reverse osmosis there are two common forms. A spiral wound configuration (**Figure 2**) uses double layers of membrane supported on a substrate as leaves wrapped around a central "product" tube. The distance between the membrane layers is usually around 30 micron, restricting the ability to handle suspended solids.

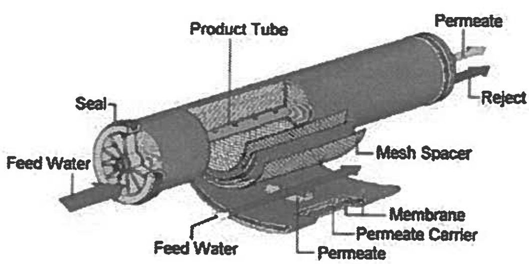

Figure 2. - Spiral Membrane Element

Where suspended material is present, a tubular membrane configuration may be used. In this version the membrane is coated on the inside wall of a pipe and filtrate passes through the pipe wall into a collection "shroud". Tube diameters are typically around ½'. (See Figure 3.)

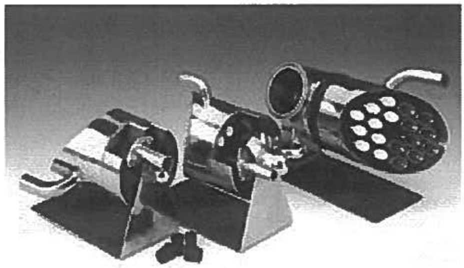

Figure 3. Tubular Membrane Module

Spiral and tubular devices are typically constructed to allow applied pressures up to 70 bar/1000 psi. With reverse osmosis, this allows dewatering up to a concentration of a saline solution until the natural osmotic pressure of the concentrate equals the applied pressure tending to limit the final concentrated water to 60,000 – 70,000 mg/l, as seen in seawater desalination membrane plant.

Application of Membrane Technologies to Drainage Water

Reverse Osmosis technology gives an opportunity to produce a good quality filtrate stream for irrigation, and a smaller volume of more highly saline "reject". The presence of calcium sulfate in the drainwater, at or near saturation levels, limits the recovery of water available in a spiral RO system. As the feed water is dewatered, the calcium salts begin to precipitate out as the concentration of salts in the retained portion rises. Crystals form on the membrane surface reducing filtration rates blocking the feed channels. Precipitation can be inhibited by the addition of "anti-scalants" but still only 50% recovery at most can be achieved.

In addition to concentration of the salts, RO will also retain almost all the Selenium, but only 50% of the boron. The high level of Boron in the filtered water would require removal by further treatment or dilution with sufficient fresh irrigation water before the filtrate could be reused for unrestricted irrigation purposes. Since water districts in the Grassland Area already dilute their fresh irrigation water supplies with recycled untreated drainwater to the point of their tolerance of boron, a boron-removal step after the membrane process will probably be required to achieve a higher in-district recycling rate.

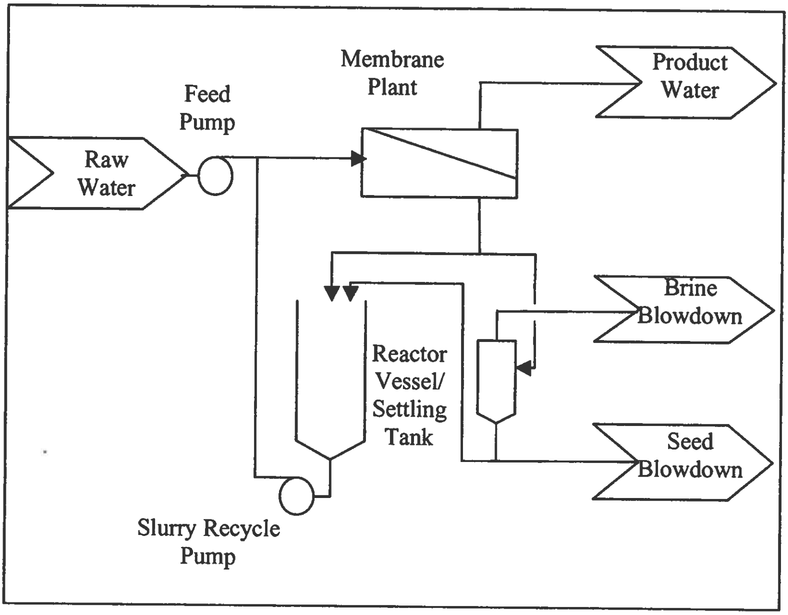

Figure 4. Simplified Seeded RO System Diagram

To overcome the calcium sulfate precipitation problem (though not applied to drainage water), a "seeded" reverse osmosis system was developed by Resources Conservation Corporation (now Ionics, Inc.) in the early 1980's. However, RCC/Ionics never advanced this process to commercial use[iii]. In the 1990's, Dr. Graham Juby et al. took RCC's work and developed a seeded RO system to treat mine drainage water in South Africa[iv] . In this approach calcium sulfate crystals are added to the incoming feed water and become the sites on which the dissolved calcium sulfate precipitate out, rather than on the membrane surface. Tubular membranes can handle the level of suspended solids present in the water caused by the crystals. The high level of Total Dissolved Solids gives the drainage water a naturally high osmotic pressure therefore requiring the reverse osmosis system to be run at high pressures generating low flux rates.

In 2001, WaterTech Partners conceived a "double pass" seeded RO process which was further developed with PCI Membrane Systems for which a patent has been submitted. Nanofiltration membranes are used to concentrate and precipitate the calcium sulfate in the drainage water ahead of an RO system. With most of the calcium salts now removed, the filtrate goes to a spiral reverse osmosis operating without the fear of calcium sulfate precipitation occurring.

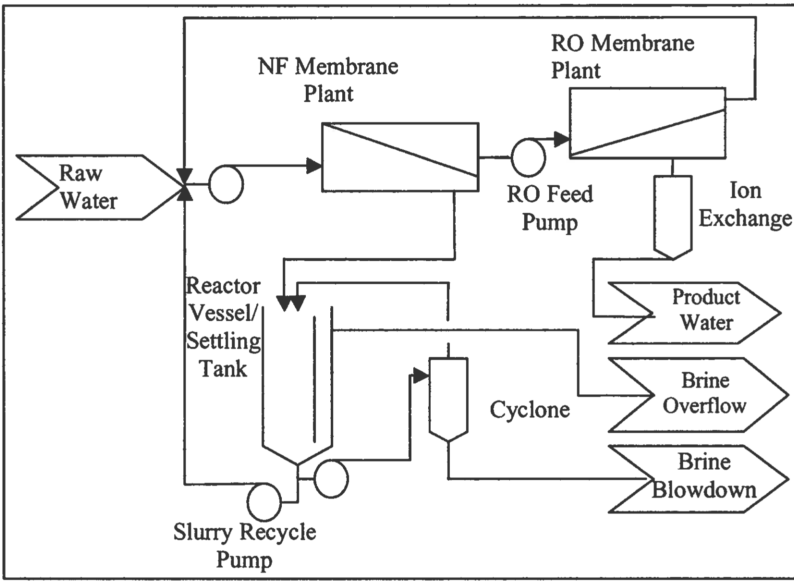

Figure 6. Simplified Schematic of DP3RO Process

The DP3RO process was first tested on actual San Luis Unit drainwater in December 2003 when a 5-gpm DP3RO pilot system was installed and placed in service at Discharge Point 25 (DP 25) in Panoche Drainage District. This system was operated for over 500 hours over a 4-month period under a grant from the Ecosystem Restoration Program of the California Bay-Delta Authority (previously known as CALFED). Preceding this pilot system project, WaterTech Partners had performed "proof of concept" bench-scale testing of the DP3RO process under a grant from the Public Interest Energy Research Program of the California Energy Commission.[5]

Feed, seeded with calcium sulfate crystals, is fed to the tubular nanofiltration plant. Filtrate from this process is filtered in a Reverse Osmosis system with its permeate passing through an Ion Exchange system to remove Boron. The reject from the RO is fed back to the front of the process to increase the overall recovery of the system. The reject from the nanofiltration system is partially returned to provide fresh seed crystals to the process, and a small volume is bled away as the

[5] This project was funded on the basis that the DP3RO process might desalinate low-TDS farm drainwater (3,000 to 5,000 mg/L) creating "new water" supplies for California with less energy per acre-foot of product water than desalinating seawater containing 36,000 mg/L TDS.

liquid reject from the plant. A liquid/solid separator removes the crystals created by the process.

<u>Options for Use of Membrane Technology as Part of the In Valley Disposal Option for the San Luis Unit</u>

Reclamation's In-Valley Disposal Option currently envisions using single-pass spiral RO membranes systems as part of its volume reduction strategy.

An initial volume reduction, would be achieved by transporting the drainwater produced on individual farms in the San Luis Unit service area to regional re-use sites where the 4,000 to 6,000 mg/L TDS farm drainwater will be used to grow salt-tolerant crops and to irrigate pasture. Such re-use sites are expected to achieve a 75% volume reduction in the farm drainwater. Subsurface tile-drain systems will be installed at the re-use sites to remove salts from these lands. The drainage water will be collected from these re-use areas and may be expected to have salinity levels in the 16,000 to 24,000 mg/L range. Selenium and Boron levels will also be at more concentrated levels in the "Re-Use Drainage water.

Reverse Osmosis systems would be installed at the re-use sites to achieve a 50% reduction in the volume of re-use site drainwater. The 50% filtered water stream at TDS below 600 mg/l will still contain levels of Boron well above the 0.7 mg/l limit for general irrigation use but the selenium and salts will be concentrated in the reject stream. Reclamation's plan is to add the desalinated and de-boronized RO filtrate water to its CVP supplies and credit the entities receiving drainage service with the value of this water at CVP water prices.

The reject from the RO plant, which might contain between 30,000 and 40,000 TDS and high levels of Selenium, would be sent to evaporation ponds. The environmental impact of the evaporation ponds would require mitigation through the construction of adjacent wetlands. The final residual from the evaporation ponds would be the dried salt requiring removal and disposal elsewhere.

Reclamation is continuing to investigate the feasibility of the above approach, including biological process to remove the Selenium from the RO reject, alongside other potential solutions. The unknown factors at this time are the sustainability of the arability of the re-use sites, the economics and volume-reduction capability of single-pass RO on the re-use drainwater, and the selenium-removal efficacy of biological processes on high TDS feedwater. Environmental concerns to this approach are focused on the large land areas required for the evaporation ponds, the environmental mitigation areas and the levels of Selenium present in standing water.

While Reclamation's proposed In-Valley Disposal Plan may be the least cost and lowest risk drainage service option currently available for San Luis Unit water contractors, a further increase in the volumetric reduction would have a number of advantages. Although the construction and operation of drainwater desalination/de-boronizing plants using the high recovery DP3RO process, as part of a drainage-service system for San Luis Unit water contractors, would in itself be more expensive than building and operating single-pass RO systems operating at a 50% water recovery rate, the higher water recovery rate would reduce the evaporation pond area by 80%, reduce the mitigation area and provide additional payback from the higher volume of recovered water. The higher levels of Selenium in the smaller volume reject water might however present an issue unless solar evaporators rather than evaporation ponds could be used. Current environmental legislation may make this difficult at the re-use sites.

If the DP3RO plants were located within the water districts, the districts could retain and use the desalinated/de-boronized product water from the DP3RO plants to displace their use of CVP water. This would make an equivalent amount of CVP water available for long-term sales to urban areas as contemplated and authorized under the Central Valley Project Improvement Act (CVPIA) enacted by Congress in 1992. With the additional income stream available to San Luis Unit contractors from selling water under CVPIA as part of a long-term drainage-service plan, application of the DP3RO process bears investigation to see if it presents a more economic and environmentally acceptable solution.

With this on farm approach, the reject stream could go to a solar evaporator. Current legislation in California enables small on farm solar evaporators to be constructed and operated under SB 1372 without having to perform an environmental impact analysis, provided certain statutory requirements and design and operating criteria that the approach is likely to achieve, are met.

Performance and Costs of DP25 Pilot

Drainwater with 8,300 mg/L TDS, 410 µg/l selenium, and 17mg/L boron was processed at 90% recovery into product water with 260 mg/L TDS, and "non detect" selenium and boron levels. The DP3RO pilot system was operated for over 500 hours and processed more than 100,000 gallons of DP#25 drainwater. While long term membrane fouling and membrane life predictions are difficult to make after only 500 hours of operation, no membrane failures occurred, calcium sulfate crystals did not block up the system, and the process was controllable in a manually operated system without difficulty.

A design and cost model for the DP3RO process shows that a 250gpm (= 1 acre-foot/day) on-farm plant operating at 90% water-recovery on 6,000 mg/L TDS feed drainwater will be able to produce recyclable high quality irrigation water (including de-boronization) at a cost under $900 per acre foot, including capital cost amortization. If $900/AF were the transfer value to urban water users of the displaced agricultural-use CVP water then this drainage-service option would become a "no cost" solution to the San Luis Unit water contractor's drainage problem. The overall cost of using this process as treatment in the re-use areas has not been calculated, but bears investigation against Reclamation's current favored plan.

Further optimization of the process is still required to assess how the process can be most effectively used as a part of the drainage solution. Nonetheless, the completed pilot project demonstrated the potential to employ the DP3RO membrane desalination/de-boronization process to achieve water-recovery rates of 85% to 90% as part of a drainage-service plan for Reclamation or the San Luis Unit water contractors.

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COMPARATIVE ASSESSMENT OF RISK MITIGATION OPTIONS FOR IRRIGATED AGRICULTURE

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ABSTRACT

The impact of reallocating water from historical agricultural uses to expanding non-agricultural uses depends crucially on how reallocation occurs. This paper examines the water reallocation problem from a Federal perspective, focusing on alternative instruments to indemnify or compensate irrigators in the event of reallocation. These include insurance strategies (crop insurance, direct payments, and new financial instruments such as tradable bonds), conservation initiatives, and market-based measures (buyouts, contingent markets, and water banks). Policy mechanisms differ in the level of compensation provided, capacity to address concerns of stakeholders, and reliance on Federal outlays. No clear "winner" emerges among the potential mechanisms to mitigate foregone irrigation returns. The merits of alternative mechanisms depend on the evaluation criteria considered, site-specific conditions, and current water institutions.

INTRODUCTION

Irrigation is a defining feature of crop production in the American West and an increasingly important element of crop production in the eastern U.S. According to the 1997 Census of Agriculture (USDA, 1999), 55.0 million acres (16 percent of cropped acres) of agricultural land were irrigated in the U.S., a 5.6 million acre (11 percent) increase over levels reported in the 1992 Census of Agriculture. The 19 Western states contain 78 percent (43 million acres) of irrigated cropland and pastureland, with the remaining 22 percent (12 million acres) in the Eastern states.

The value of crop sales, which measures the value of commodities leaving the farm gate, indicates the importance of irrigation water to farming and rural areas. Based on calculations from the 1997 Census of Agriculture, an estimated $98 billion of crop sales were produced on 309 million acres of harvested cropland in the U.S. Irrigated crops occupied 16 percent of that area, but accounted for 49 percent of the total value of crop sales from U.S. farms and ranches. Average sales per harvested acre were $950 for irrigated cropland, compared with $200 for non-

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irrigated cropland. Irrigated crop sales were highest for orchards, vegetables, and nursery crops, while irrigated cropland area was dominated by grain and forage crops, primarily corn for grain and alfalfa hay.

In the 19 Western states, the 1997 Census reported 142 million acres of harvested cropland with total crop sales of $45 billion. Irrigated crops in the West accounted for 27 percent of the area, but produced 72 percent of the total value of crop sales. The sales of Western irrigated crops totaled about $32 billion in 1997, or roughly one-third of all U.S. crop sales. Crop sales per harvested acre in the West averaged $850 for irrigated cropland and $122 for non-irrigated cropland. As was the case at the national level, irrigated crop sales in the West were led by orchards, vegetables, and nursery crops, while irrigated cropland area was dominated by grain and forage crops.

As urban and environmental demands for water grow, there will be increased competition for water historically used by agriculture. This competition may change the economic mix for regions with significant agricultural sectors, especially in the West, where water-supply development opportunities are limited.

The impact of reallocating water from historical agricultural uses to higher-valued agriculture and to expanding non-agricultural demands depends crucially on how this reallocation takes place. In most areas, the water allocation systems are controlled by institutions that currently are not able to respond to market signals. This lack of flexibility makes it difficult for water use to smoothly transition from agriculture to new higher-valued uses and for water-right holders to retain the full value of their rights in the event of a reallocation. Such losses have increased demands to compensate right holders (usually farmers) for lost water supplies. Due to uncertainty regarding water supplies, reallocation quantity and timing is uncertain, and the prospect of reallocation introduces an element of risk that may influence farmers' production decisions. The magnitude of agricultural income losses, of economic losses more broadly, and of costs to Federal and local governments, depends on how water transfer systems evolve and how current users are compensated for the loss of historic water supplies.

This paper examines the water reallocation problem from a Federal perspective, focusing on alternative ways to indemnify or compensate irrigators in the event of reallocation. The Federal perspective is important because Federally supplied water (Bureau of Reclamation) is often the source of the reallocated supply, Federal agency actions are often the impetus for reallocation, and Federal programs are often called on to provide compensation. The discussion of alternative policy instruments to compensate irrigators addresses 1) potential Federal expenditures, 2) the extent to which each policy can be expected to reduce agricultural water use and augment in-stream flows, and 3) the effectiveness of policies in mitigating financial harm to irrigators.

THE ROLE OF FEDERAL DECISIONS

The Federal role in the development and allocation of irrigation water supplies has evolved over time. Federal authority for water resources was established in early legislation to promote economic development through the Federal reclamation, hydropower and navigation programs. More recently, the focus on large-scale capital construction projects has given way to multi-objective management of river ecosystems, with greater emphasis on trust responsibilities and environmental concerns. The evolving Federal role—and its relation to established water rights under state law—continue to play out in river basins across the West.

Congressional mandates and legal statutes over the past century have substantially redefined the scope and role of Federal agencies in the management of river systems. Increasingly, Federal actions have prompted reallocation of water supplies—primarily from agriculture—to meet Federal responsibilities for endangered species protection and other purposes.

The probability that future Federal actions will restrict irrigation withdrawals depends on many factors, including: weather factors relating to drought; the capacity of the water storage and delivery system; future water demands; the flexibility of legal institutions in accommodating water-supply shortfalls; and the extent and nature of Federal interests in the basin.

The rationale for Federal indemnification of potential producer losses will depend in part on the nature of the Federal action. Federal water decisions associated with endangered species protection are likely to occur unexpectedly. Unanticipated weather, for example, may lead to species threats that must be addressed immediately. However, Endangered Species Act (ESA) restrictions will most likely coincide with natural drought events, making it difficult to distinguish drought impacts from the effect of Federal actions.

Changes in water allocations associated with the settlement of Native American water rights or other Federal Reserved rights may not pose as serious a 'single-year' indemnification issue because water reallocations generally will be known prior to crop planting. However, compensation for foregone returns still may be at issue. In the case of a permanent water loss, the decline in asset values may be a more appropriate measure of compensation than estimates of annual income loss. While water transfer volumes may be fixed and certain, basin reallocations to meet these claims can have broader risk implications for irrigated producers. Measures that reduce the dependability of agricultural water supplies may increase future risk exposure and heighten the likelihood of 'single-year' indemnification.

POLICIES TO MITIGATE WATER INTERRUPTION LOSSES

Various policies have been proposed to mitigate agricultural losses from water-supply reductions. These include insurance strategies (crop insurance, direct payments, and new financial instruments such as tradable bonds), conservation initiatives, and market-based measures (buyouts, contingent markets, and water banks). Policy measures differ in the level of compensation provided, capacity to address concerns of direct and indirect stakeholders, reliance on Federal outlays, required institutional modifications, and impacts on production and water-use efficiency.

Insurance Mechanisms

Both the costs and consequences of providing insurance or direct payments to farmers who face the risk of water supply reductions due to reallocation depend in part on the insurance strategy or payment mechanism employed. Possible insurance mechanisms include subsidized insurance (similar to that already offered by USDA's Risk Management Agency (RMA) for weather-related yield and price risks), direct compensation (similar to disaster assistance), and market-based insurer tools such as tradable contingent bonds.

Subsidized Insurance: RMA currently offers subsidized crop insurance to protect participating farmers against specific weather and market-related shortfalls in crop yields or revenues. A suite of insurance contracts provide indemnity payments in the event of particularly low yields and/or prices. The current provisions, however, do not cover yield losses that stem from the cancellation or reallocation of irrigation water supplies unless it is instigated by a natural event (e.g., drought). Moreover, insurance coverage is available only for certain crops.

One way to insure farmers against water shortage risk would be to alter the current insurance program so as to include coverage of potential losses stemming from Federal actions that restrict water allocations. While superficially straightforward, adjusting the current program could also entail substantial difficulties, unintended consequences, and institutional and administrative costs.

First, unlike weather-related price and yield variation, no historical data exist that could be used to systematically estimate the likelihood of mandatory water reallocation. Under the current agreement between the Federal government and private insurance agencies, insurance companies pay a portion of the indemnities and retain a portion of the premiums. If the probability and potential damages of Federal water reallocations cannot be assessed in a reliable manner it will be difficult, if not infeasible, to calculate new premiums that satisfy both the government and private insurance companies.

Second, if farmers are insured against downside losses in the event of water reallocations, they may choose to plant crops that would not normally be as profitable as current crops, but with higher indemnity potential under water supply restrictions. For example, once insured, farmers may elect to plant high-value, high-investment crops, knowing they would be compensated for their lost investment in the event of water-supply restrictions. If farmers do not pay the actuarially fair premium for such potential losses, then altered cropping patterns of this type could be very costly to the government. If the premiums were subsidized, as they are under the current program, the program would instill incentives of this kind. If the premiums were not subsidized, insurance may provide farmers insurance against the risk of single-year reallocation, but would not compensate them for the potential loss of their water rights.

Catastrophic Coverage and Noninsured Crop Disaster Assistance: Under a combination of the Noninsured Crop Disaster Assistance Program (NAP) and the minimal crop insurance program, farmers can obtain "catastrophic coverage" that insures weather-related losses greater than 50 percent of expected yield at 55% of the average market price. Participating farms can obtain this coverage for just $100 per county and crop insured, regardless of how many acres a farmer insures in a given county. Like the "full" crop insurance program, coverage does not currently extend to losses that stem from a reallocation of water. An expansion to cover water shortfalls could entail an ambiguous and potentially large increase in government expenditures while compensating farmers for a relatively small share of the per-acre losses that stem from water reallocations.

Direct Compensation: Congress may choose to compensate farmers in an *ad hoc* fashion in the event of water reallocations, as it occasionally does in response to certain weather-related losses. With direct payments adjusting crops in anticipation of a loss is potentially a concern, except farmers pay no premiums, and have no assurance of compensation in the event of loss.

Tradable Contingent Bonds: Rather than provide individual insurance contracts or direct payments to farmers, the government might insure farmers through an auction of tradable bonds that pay a predetermined value in the event of Federally-imposed, water-supply restrictions. For example, suppose the government wishes to provide a total of $1 million in insurance coverage against a possible reallocation of water in a particular region over the next ten years. To achieve this objective, an Agency could auction one thousand $1000 bonds, each of which pays the face value in the event water is reallocated. The competitive price of the bonds, determined via auction, is the conceptual equivalent of the premium paid in insurance contracts. The number of bonds a farmer chooses to purchase would determine his or her level of coverage. If a farmer later wishes to change coverage levels due to a change in crops, prices, or growing practices, the farmer can do so by buying (or selling bonds) from (to) other farmers.

Unlike insurance or direct payments, tradable contingent bonds do not give farmers an incentive to alter their production artificially in order to take advantage of the program. Further, the compensation costs of water reallocation would be known in advance—the amount would equal the face value of bonds issued.

The non-distortionary nature of tradable contingent bonds constitutes a potential benefit of this approach. Another benefit is that a bond market would preclude administrative costs associated with determining premiums and selling individualized insurance contracts. Furthermore, farmers indirectly affected by water reallocations could also insure themselves. For example, farmers down-slope from farmers who irrigate with Federal water may benefit indirectly to the extent that up-slope irrigation replenishes down-slope supplies. Down-slope farmers could also purchase bonds to insure themselves against potential losses. Similarly, input suppliers and other local agricultural interests who indirectly hold personal stakes in water allocations could insure themselves.

Government officials may also choose to allocate some or all of the bonds (rather that sell them via auction), perhaps according to farmers' current water rights. Allocated bond distribution would increase the net costs to the government, and require an initial allocation of the bonds according to some criteria.

Agricultural Water Conservation Policies

Production adjustments to conserve water supplies at the farm level may help to mitigate the effect of cutbacks in irrigation water deliveries. The extent to which these measures can offset producer losses will depend on many factors, including the nature and timing of the water-supply restriction, the crops produced on the farm, the farm technology and resource base, hydrologic conditions in the basin, and state regulations governing water conservation.

Agricultural water conservation can be achieved through several means. Within an irrigation season, producers may reduce per-acre water use for a given crop through deficit irrigation. If information on water shortages is available before the crop is planted, more options are available, shifting to alternative crops or lower-yielding varieties of the same crop that use less water, or adopting more efficient irrigation technologies. In some cases, producers may convert from irrigated to dryland farming or retire land from production.

Deficit irrigation—knowingly applying less than full crop-consumptive requirements and accepting the corresponding yield loss—may be an option in areas where the loss in irrigated yield is low relative to the value of water saved. Deficit irrigation can be an effective potential producer response where water restrictions are imposed later in the crop season, particularly for drought tolerant crops and other perennial crops and pasture under moderately arid conditions.

The ability to substitute crops is an important response to water shortfalls that are known prior to the planting season. Wide variation in irrigated crop sales values (USDA, 2003) reflects significant flexibility for irrigated agriculture to adjust to changes in water availability through cropping adjustments. Farmers may also adjust to water shortages by growing less water-intensive crops, thus extending limited water supplies over a greater area.

Many irrigators have responded to water scarcity through the use of improved irrigation technologies—often in combination with other water-conserving strategies—and irrigators may look to technology as one of several means of conserving water in the future. Improved water management practices may also be required to achieve the efficiency potential of the physical system. Providing incentives to farmers to adopt more efficient irrigation systems is a common policy proposal for augmenting scarce water supplies in the West.

Improved irrigation and water conveyance technologies that increase onfarm water-use efficiency can have potential benefits for water conservation, water quality and farm returns (Schaible, 2000). However, the extent to which technology adoption can achieve significant water savings for in-stream uses will depend on many factors, including levels of efficiency improvement, the disposition of irrigation losses and return flows, and changes in crop consumptive use, both on-farm and downstream (Aillery and Gollehon, 2000). Improving irrigation technology alone may not achieve the desired reduction in agricultural water use and increase in streamflow, without accompanying reductions in crop consumptive use and irretrievable system losses. The effectiveness of improved on-farm irrigation technology will depend on the objectives of the water-conservation policy. For example, if the goal is to augment flows in a specific stream reach at a specific time of the year, increased on-farm efficiency can be effective provided that diversions are reduced and 'conserved' water is not intercepted before flowing through the critical reach. However, if the goal is to increase total outflow from a watershed, improved irrigation application technologies will often lead to higher consumptive water use, reduced return flows, and a net reduction in basin outflows. Thus, the effectiveness of on-farm water conservation policies to offset reductions in water supplies cannot be easily generalized without considering hydrologic conditions, water diversion rights, and policy objectives for the basin. Conservation programs that target flow augmentation for in-stream environmental uses will often require water-right reforms and regulations to ensure allocation of conserved water for the desired purpose (Schaible and Aillery, 2003; Willis et al., 1998).

Market-based Measures

Differences across crops in per-acre returns to irrigation suggest that market-based policies that facilitate transfer of water from lower- to higher-valued uses will minimize crop revenue losses while meeting other short-term water needs. Market-based policies can involve irrigators as both buyers and sellers of water supplies, as well as Federal/State governments and environmental organizations, depending on the structure of the mechanism.

Buyouts: Rather than compensate farmers for "losses" associated with a reallocation of water, the government might purchase farmers' water rights prior to, or at the time of a water shortfall. Buyouts of farmland and irrigation water rights may be highly effective in redirecting flow to the desired target while compensating farmers for foregone crop returns.

There are problems with using buyouts for reallocations. First, water savings from the buyout must not be intercepted by other users with an unsatisfied water allocation. This can be a significant issue during drought conditions when many irrigators may be experiencing water shortages while streams are flowing with buyout water for instream use. Second, proposed buyout programs generally rely on the Federal government for financing. For example, one recent Congressional proposal [H.R.5698 §3(g)(1)] called for the Federal government to finance up to 75 percent of buyout costs. Third, permanent buyout policies are often infeasible because of concerns expressed by local communities and politicians that the buyouts would have negative impacts on regional agricultural employment, farm-related businesses, and local tax bases (Hymon, 2002). Consequently, although many farmers may be willing sellers, local agribusiness and community interests may oppose buyout policies. For example, a buyout proposal formulated by conservation and agricultural groups was dropped in the Klamath Basin, even though 24 farm families controlling 30,000 acres were offering to sell land and associated water (ONRC, 2001).

Water Banks: Water banks have been established by several states to promote more efficient water distribution during droughts. Water banks are designed to facilitate the temporary reallocation of water among interested parties by lowering the transaction costs of effecting water transfers. The "bank" serves as a broker for water transfers by drafting both purchasing and sales contracts—usually at fixed prices—and coordinating the transfers. This enables both water buyers and sellers who wish to buy (sell) for the fixed price to rapidly complete the sale. For example, the California Department of Water Resources (DWR) operated Drought Water Banks in 1991 and 1992 (Howitt, 1994; Israel and Lund, 1995).

The degree to which State water banks can be used to increase in-stream flows for other uses depends on state institutions. State laws and regulations may create severe impediments and disincentives to sell bank water for nonagricultural purposes (Huffaker, Whittlesey, and Wandschneider, 1993). Associated with all water transfers is the problem that transferred water needs to be protected against further appropriation by downstream irrigators who would otherwise use the flow.

Contingent Water Leases: Contingent water leases have the potential to limit the extent and duration of the negative economic impacts that permanent transfers may have on agricultural uses as well as local communities and water users not party to the trade (Huffaker and Whittlesey, 2000). Contingent water leases, which transfer water when triggered by a predetermined event, secure an option to water supply for environmental and urban uses. Contingent leases operate via a contract, that gives buyers temporary use of the water whenever a given contingency occurs (such as a drought). The seller (e.g., the farmer) retains ownership of the water right and receives his/her normal water supply during years when the option is not exercised. When the option is exercised, the seller leases to the buyer a given portion of water under the right for a specified period of time. Buyers may be other farmers, other users (public water systems or hydroelectric plants) or public agencies seeking instream flows. Both parties benefit: the buyer obtains a secure water supply during the contingency, and the farmer-seller is paid for the option and maintains secure long-term water supplies that allow for continued operation and long-term financing. This also protects the long-term agriculture base of local communities. The water transferred under the lease is temporary and thus potential injuries to local communities are short-lived.

Pioneering work by Hamilton et al. (1989) analyzed contingent water transfers as a means of increasing the production of "firm" power in the Snake River system. Based on their study of the historic hydrograph of the Snake River system, the authors estimated that increasing the assured annual flows by 12 percent over the lowest recorded flow would invoke the contingency (i.e., require interruption in an irrigator's use) to some irrigators in 2 of 10 years and only 1 year in 51 would all the contract water be required. The results indicate that contingent water transfers would be economically feasible in the region because estimated hydropower benefits were estimated to be 10 times greater than lost farm income.

The work by Hamilton et al. (1989) which was extended by Hamilton and Whittlesey (1992), demonstrates another advantage of contingent water markets: they can be financially self sufficient in executing water transfers without requiring Federal loans, grants, and crop insurance or non-insured assistance. The task is to find buyers that can benefit commercially from increased in-stream flows managed for endangered species, such as hydropower producers.

Proposals incorporating short-term leases and contingency aspects are being introduced in the Klamath River Basin. For example, the joint proposal announced by conservation and farm groups in June 2001 has developed into a new initiative in which the Federal government would pay $2,500/acre for permanent "water easements" (Milstein, 2002). Participating farmers would sell their rights to irrigate in dry years, but could continue to irrigate in wet years. In another example, the Bureau of Reclamation is entering the second year of a pilot project in which it leases water from ranchers in Oregon's Wood River Valley to increase inflow to the Upper Klamath Lake (Harper, 2002). In a third example, a private landowner and the Oregon Water Trust formulated a 'split-season' lease of the landowner's water right (Oregon Water Trust, 2002). The lease calls for the landowner to irrigate for a first cutting of hay from April to July, then the landowner foregoes additional cuttings, leaving the remaining water quantity of the right as instream flow for fish passage. So far, no proposal has recognized the potential for contingent water markets to be financially self-sufficient.

Water Markets: A strong argument can be made in favor of market-based mechanisms to reallocate water among current and proposed uses, as demand for these uses adjusts under changing water-supply conditions. Operational water markets would allow farmers and other interests to insure themselves against uncertain deliveries (due to weather or other water restrictions on agricultural and non-agricultural users), providing compensation to those with historical ownership of water rights, while at the same time reducing inefficiencies embedded in the current allocation system. Implementing full-functioning water markets, however, would need to address major physical and institutional hurdles governing water allocation. In most cases, modifications of State water laws and Federal project-level administrative procedures would be required to allow for water market transfers by: (1) allowing private parties or downstream communities to lease water rights for in-stream flow augmentation; (2) relaxing restrictions and disincentives impeding water transfers in general; (3) better protecting in-stream flows from unauthorized diversions, and (4) explicit consideration of the interests of indirect stakeholders in current water allocations. The physical, institutional, and political costs of developing such a system ultimately may be high.

Variants of market-based solutions might be used to compensate farmers while simultaneously removing some inefficiencies in resource use. Federal or State government, perhaps in conjunction with third parties (e.g., environmental interests), might accept competitive bids for contingent water leases to meet short-term water needs. Alternatively, water banks can be developed to serve as a market intermediary. Such mechanisms would allow water to move from its lowest-valued use when water is most needed for annual in-stream flows or other uses during periods of restricted water supplies. Farmers would thus be compensated for the water supply diverted while encouraged to account for the risk of water shortfalls in their production decisions. These mechanisms, however, would entail some of the same institutional hurdles as a full-fledged market.

FINAL CONSIDERATIONS

This paper reviews, from a Federal perspective, possible policies to address the risk to irrigators of reduced water availability. Several policy mechanisms are assessed considering: 1) the potential Federal expenditures, 2) the extent to which stream flow augmentation might be achieved, and 3) their effectiveness in mitigating financial harm to irrigators. While Federal water-resource agencies have reallocated water supplies to meet changing needs, the Federal role in providing compensation remains unclear. Many, if not most, of the policy mechanisms would include changes in Federal and State policies, water management institutions and infrastructure, as well as evolving attitudes governing water use.

Potential Federal budgetary outlays will vary by policy mechanism depending on several factors, including: the geographic coverage of water supply restrictions; water demands of competing uses (which influences the magnitude of losses); the share of the irrigation loss that is compensated; the degree to which costs are shifted to other water uses (as with power generation in a contingent market case); and the value of more efficient resource allocations possible in market solutions. For a given quantity of water, Federal costs are likely to be lowest for contingent markets and auctioned tradable bonds, as a portion of the cost is shifted to current water users. Costs are likely to be high for buyouts that acquire irrigated land and appurtenant water rights. Federal costs may range from moderate to high with direct compensation, subsidized insurance, allocated tradable bonds, and agricultural water conservation, where compensation levels are often influenced by non-economic considerations.

The extent to which policy mechanisms could be used to secure water for increased instream flow will depend on legal and institutional adjustments. Mechanisms that engage individual irrigators may be more effective if given the flexibility to geographically target key hydrologic areas. Buyouts, contingent markets, and tradable bonds all are readily targeted to limited areas, and may utilize price incentives to encourage participation. Mechanisms such as state water banks and national water conservation initiatives may not necessarily provide water in the needed areas or in specified amounts, and may be less effective in meeting local reallocation objectives, especially when monitoring of withdrawals is costly or impossible.

Finally, alternative mechanisms differ in their capacity to mitigate financial harm to irrigators. Market mechanisms have a clear advantage when measured according to this criterion, since exchange does not occur if the compensation is inadequate. Allocated tradable bonds may also effectively offset losses if the allocation process is designed to provide full compensation. Since insurance premiums and auctioned tradable bonds are purchased, irrigators incur expenses, with the amount dependent on the level of insurance or auction subsidy. Direct compensation can provide full (or more than full) replacement of lost revenue, depending on the compensation levels established by the political process. Existing catastrophic insurance provides relatively little compensation due to the design of the program which limits payments. Incentives for agricultural water conservation may help prevent the need to transfer water where field-level savings translates to increased streamflow. However, existing conservation programs do not provide compensation when an actual transfer occurs.

Increasing competition for water—resulting in part from Federal actions—will most certainly affect the irrigated agricultural sector. Voluntary, market-based mechanisms have the potential to provide total compensation at the lowest cost. However, no clear "winner" emerges in the examination of potential policy mechanisms to mitigate the effects of foregone irrigation returns. The extent, value and local characteristics of irrigated production have important implications for framing policy that would compensate producer losses from water supply restrictions. The merits of alternative mechanisms depend on the evaluation criteria considered, site-specific conditions, and current water institutions.

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A MULTI-VARIABLE APPROACH FOR THE COMMAND OF CANAL DE PROVENCE AIX NORD WATER SUPPLY SUBSYSTEM

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ABSTRACT

The Canal de Provence is fully user oriented. Water users can take the water freely without respecting neither rotation nor any sort of priority allocation. Its structure, consisting of main free flow canals and pressurized distribution networks, is well adapted to this strategy. The main canal must be able to face the regime variations coming from this kind of distribution. The current regulation conception first split the whole system into a series of assumed independent sub-systems. The multi-variable aspect is then taken into account by a coordination of the sub-systems adjustment, carrying the discharge correction from downstream to upstream.

The Aix nord branch control presents interesting characteristics such as many different hydraulic entities (free surface canals, reservoirs, pumping stations) and operating constraints (levels in reservoirs, optimization of pumping costs). A real multi-variable approach will allow managing all gate and pump operations and all constraints at the same time, leading to a global optimisation of the whole system.

The MIMO (Mulit Input – Multi Output) model is established from transfer functions, the coefficients of which are deduced from the physical and geometrical characteristics of the system. A Linear Quadratic Regulator is computed and tested on a complete non-linear numerical model of the hydraulic system. The system to be controlled includes many discrete commands (pump operations) that are not managed by a classical optimal control. These commands are treated apart, leading to calculated perturbations that are introduced in the regulator.

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INTRODUCTION

The control of a canal system is a MIMO control. Usually, in field applications, the design starts from a Single Input Single Output (SISO) design, and the MIMO character is added after by an ad hock procedure, like coordination between pools. Many studies of MIMO control, in particular optimal control, on canal automation have been done (Corriga 1982, Malaterre 1994 and 1998). A survey can be found in Georges and Litrico (2002). In real cases, the complete control problem must take into account field and operational constraints that are not easily handled by the usual approaches.

The application we present here concerns the first study of a MIMO controller on an existing canal branch. We have chosen a branch with interesting characteristic for the experimentation of this kind of control. The reasons for the selection of the Canal de Provence Aix-Nord branch are the multiplicity of structures of different kind and the existing management constraints.

The Aix-Nord branch is presented in the next section with the hydraulics variables, which are the control, controlled, perturbation and measured variables. In the same section will appear the exploitation constraints, which are important for the control implementation.

A linear modelling of the system is performed in section 3. This modelling starts from transfer functions. Its validity has been verified in the Canal de Provence experience on irrigation canal control. The design of the controller takes place in section 4 and the results in regulation and tracking regarding the Aix-Nord branch are shown in section 5.

The simulations and tests of performance of the controller are carried out on the full non-linear simulation model Sic of the Cemagref, which can model a canal system by solving the Saint-Venant equation with implementation of control structures and perturbations (Sic 1992).

THE HYDRAULIC SYSTEM

Description of the system

The Aix-Nord branch consists of a 10 km (6.2 mile) long canal, nine reservoirs and five pumping stations. The sub-system we are interested in is shown schematically on Figure 1.

A gate at the output of the regulation pool controls the discharge in the Trevaresse canal. This canal has been recently modernized by the construction of a series of duckbill weirs. This canal feeds the 13,400 m^3 (10.9 acre-foot) Barounette reservoir, from which a pumping station feeds the 8,500 m^3 (6.9 acre-foot) Collet-Redon reservoir.

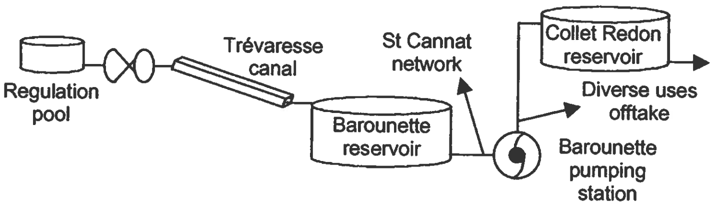

Figure 1. Outline of the hydraulic system

Hydraulic variables

The hydraulic variables and their notations are the following:
Control variables or inputs:

- The discharge at the output gate of the regulation reservoir, u_1.
- The discharge of the Barounette pumping station (4 pumps), u_2.

Controlled variables:

- Volume of the Barounette reservoir, y_1.
- Volume of the Collet Redon reservoir, y_2.

Measured variables:

- Discharge downstream of the Trevaresse canal, z_1.
- Volume of the Barounette reservoir, $z_2 = y_1$.
- Discharge at the output of the Barounette reservoir, z_3.
- Volume of the Collet-Redon reservoir, $z_4 = y_2$.

Perturbations:

- Leakage out of the canal, w_1.
- Outlets upstream of the Barounette pumping station, w_2.
- Customers outlets downstream of this pumping station, w_3.
- Output discharge of the Collet Redon reservoir, w_4, which is measured.

Constraints

The application shown here deals with many kinds of constraints:

- The Trevaresse canal capacity is 1.5 m^3/s (53 cfs). However, so as not to empty the canal (important filling time), a minimum discharge of 30 l/s (1.1 cfs) is needed.
- The target volume of the Barounette reservoir is 9,000 m^3 (7.3 acre-foot).

The operation of the Barounette pumping station is the more complex one. This station is made of four parallel pumps, working independently on an on/off basis.

- Concerning the downstream Barounette reservoir, four low levels exist which forbid the running of 1, 2, 3 or 4 pumps.

- A maximum (7,700 m^3) and a minimum (4,000 m^3) volume exist for the Collet Redon reservoir. The Barounette pumping station works so that to reach the high level at the end of the off-peak period. During the peak period, a prediction is performed and based on the result, one, two or three pumps are switch on.
- An optimization of energy cost is performed. Without detailing the variation of energy prices, let us simply say that this price varies according to the period in the year and also to the time in each day. The electricity price can vary by a factor of 4 throughout the year.

In this application, only a few of these constraints will be treated.

THE SYSTEM MODELLING

In order to design a MIMO controller, we need a linear modelling of the whole system. This modelling makes use of:

- The second order transfer function between upstream and downstream discharges of the canal already proposed by Deltour (1988).
- Balance relations between discharges and volumes of the reservoirs

The upstream-downstream discharges transfer function is a second order one with double pole:

$$F(z) = \frac{N}{1 - Dz^{-1}} z^{-r}$$

with

$$D = \exp(-T_e / T)$$
$$N = (1 - D)^2$$

T_e is the control time step and T is a time constant characterizing the canal, r is the pure delay expressed in number of time steps. These two last quantities can be related to the global hydraulic delay $\Delta V / \Delta Q$ by (see Figure 2):

$$\frac{\Delta V}{\Delta Q} = T + rT_e$$

Here ΔV is the steady state volume variation due to a ΔQ discharge variation. This kind of parameterization is already in use at the "Société du Canal de Provence" since about 30 years and has proven its validity (Rogier 1987, Deltour 1988, Deltour 1998)

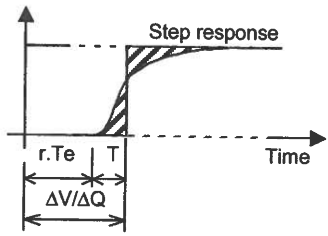

Figure 2. Characteristic times of a canal

The pure delay itself is given by the time needed for a small perturbation to travel from upstream to downstream in the canal:

$$rT_e = \frac{L}{v+c}$$

with L the length of the canal, v the flow speed and c the celerity of hydraulic waves. The great advantage of this transfer function is that it is not the result of black-box identification and depends only on geometrical and physical features of the canal, with no free parameter. Figure 3 shows the downstream response to an upstream input of pseudo-random binary series (PRBS) type around a 700 l/s discharge value. This type of response is a good test for a system modelling because the rich spectral content of a PRBS (Landau 1993, Ljung 1999). In Figure 3 the result is compared with a Sic modelling of the canal. The agreement is very good.

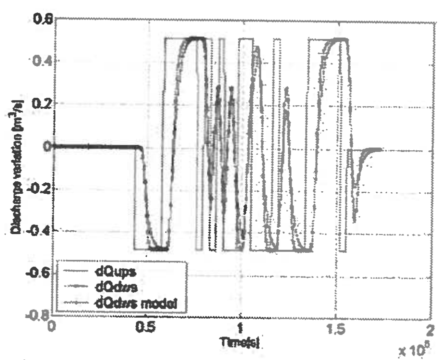

Figure 3. Comparison of downstream response discharge to an upstream PRBS dQdws is the Sic result

The modelling of the reservoirs is simpler since they are basically integrators. A discrete time approximation can lead to the following discharge-volume transfer function:

$$F(z) = \frac{T_e}{2}\frac{1+z^{-1}}{1-z^{-1}}$$

The above expressions represent a careful modelling of the hydraulic system, which is required for an efficient control design.

DESIGN OF THE CONTROL

Optimal or LQG control

In order to design a MIMO LQG controller, we shall need a state space description of the system. Starting from the above transfer function description, a minimal state space realisation can be achieved using the specialised routines of Matlab. However, since we need null static error in regulation, integrator type variables must be added (Malaterre 1994,1998). The state equations then take the classical form:

$$\begin{aligned} X^{+} &= A_s X + B_u u + B_w w \\ y &= C_y X + D_{yu} u + D_{yw} w \end{aligned}$$

X, *u*, *y* and *w* are respectively state, control action, controlled variables and perturbation vectors. $A_s, B_u, B_w, C_y, D_{yu}, D_{yw}$ are matrices of appropriate dimensions. The optimal control is obtained by the minimization of a criterion:

$$J = \frac{1}{2}\sum_{k=0}^{N-1}\left[(X(k)-X_c(k))' Q_X (X(k)-X_c(k)) + (u(k)-u_c(k))' R(u(k)-u_c(k))\right]$$

X_c and u_c are the wanted set point trajectories for *X* and *u*, respectively. An extensive development of the design of the control can be found in Åström and Wittenmark (1997), Malaterre (1994, 1998), Georges and Litrico (2002). The command *u* is obtained under the form:

$$u = -KX + H$$

where the gain matrix *K* is, in our application, solution of the asymptotic Riccati equation, and the pre-filter *H* is dependant on the open-loop or anticipatory part of the control.

Observer construction

The above control law assumes that the state vector X is known, which is almost all the time unrealistic. Most frequently, certain combination of states, or observed variables z, are effectively measured:

$$z = C_z X + D_{zu} u + D_{zw} w.$$

From variables z, the state vector X can be reconstructed, (Åström and Wittenmark 1997, Malaterre 1994,1998). Then X is replaced by the reconstructed one, $\overline{X}$. Due to unknown perturbations, a state Kalman filter including a perturbation observer is designed:

$$\overline{X}^{+} = A_s \overline{X} + B_u u + B_w \overline{w} + L(z - \overline{z})$$

where $\overline{w}$ is the perturbation vector estimation:

$$\overline{w}^{+} = \overline{w} + L_w (z - \overline{z})$$

L and L_w matrices can be computed through the minimization of the reconstruction error (Kalman filter)

APPLICATION TO THE AIX-NORD BRANCH

Tuning of the parameters

The scenarios we tested are without prediction on perturbations, which represent the most difficult cases for the control. Tuning parameters are the various Q and R matrices appearing in the criterions of the control and of the Kalman filter of the observer. These matrices are chosen diagonal, with diagonal elements according to the Bryson rule (Bryson 1975, Larminat 1993):

$$R_{ii} = (1/\sup(u_i))^2$$
$$Q_{ii} = (1/\sup(y_i))^2$$

where $\sup(u_i)$ and $\sup(y_i)$ are the on-field physical magnitude of the corresponding control actions and controlled variables value. These values serve as starting points for trial and error refinement of the parameters.

A regulation scenario

We simulate first a regulation scenario, where unpredicted step w_2 and w_3 perturbations occur and no w_1 perturbation, as shown in Figure 4. The purpose of this test is to appreciate the ability of the controller to reject perturbations.

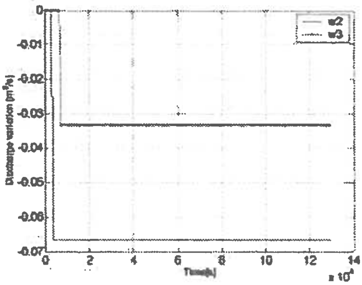

Figure 4. Step perturbations w_2 and w_3

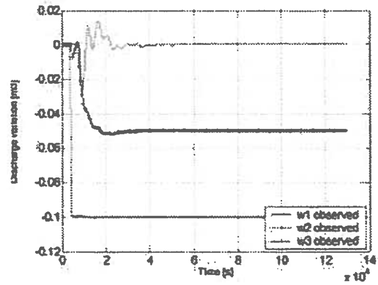

Figure 5. Reconstructed perturbations

The performance of the observer can be seen in Figure 5 where reconstructed perturbations are displayed. The step perturbations are rapidly recovered. One can notice also that w_1 is reconstructed with a low value and returns rapidly to zero. Figures 6 and 7 display respectively the volume variations in the reservoirs and the control action variables. As can be seen, the regulation performances appear satisfactory.

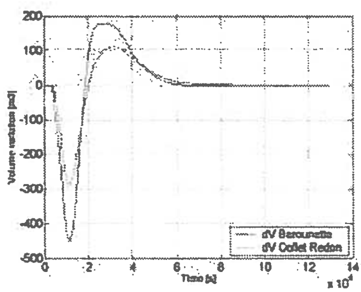

Figure 6. Reservoir volumes variations

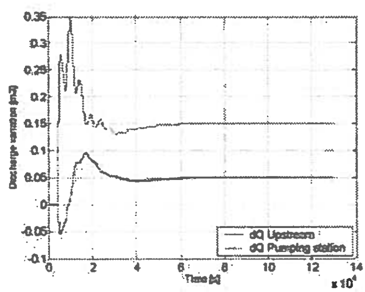

Figure 7. Control action variables

A Tracking Scenario

Tracking scenario must be tested since, as we explained in the description of the hydraulic system, set points for the reservoirs can change through time due to conditions like the variation of demand or variations of energy prices.

Figure 8 shows the response to an instantaneous set point change, with same parameter set as the regulation case. The new set points are reached rapidly with no important overshooting.

The control variables variations are shown in Figure 9. As expected, in the transient duration period, these variables vary more rapidly than in the regulation case, even if they remain operationally consistent.

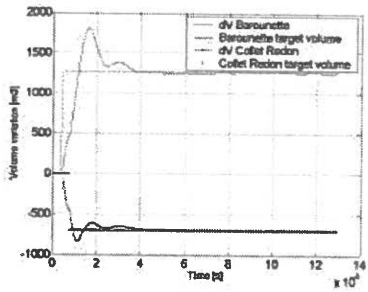

Figure 8. Reservoir volumes variation in the tracking scenario

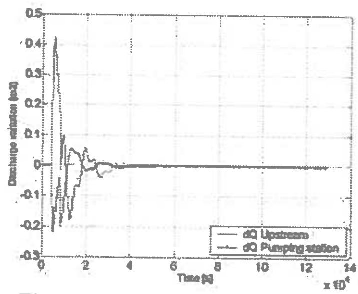

Figure 9. Input control variables

Finally it is interesting to look at the reconstructed perturbations, even if, in this scenario, it is not a crucial point. No perturbations are present. Figure 10 shows that, indeed, after a transient period, where the reconstructed perturbations vary around zero, they vanish in the steady state.

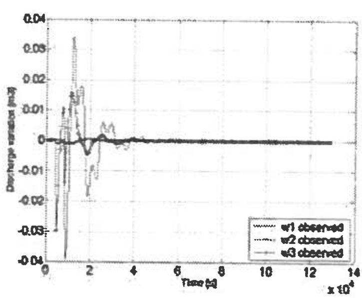

Figure 10. Reconstructed perturbations in the tracking scenario

CONCLUSION

The optimal control we have proposed aim to take into account the whole multivariable character of an irrigation canal control. This needs first a careful design of the system. However, for control purposes model is required to be as simple as possible. The modelling we proposed in section 3 fulfills these conditions. The controller appears to work well. Nevertheless, prior to field implementation, one must make sure that it provides a benefit in relation to the actual SISO automation. Further studies are planned since the field operators are not, in general, specialists of system control. In the next step, discontinuous values of discharge in the pumping station will be incorporated in the control.

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RURAL ELECTRICITY'S EFFECT ON WATER SUPPLY AND AGRICULTURAL PRODUCTIVITY

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ABSTRACT

There is increasing concern relative to the availability of food and water to meet the needs of the world's future population. The availability and use of electricity increases income and reduces malnutrition. The rural poor can benefit most from the increased availability of electricity. The use of electricity improves the efficiency of irrigation and promotes pumping from rivers and canals. Water becomes available to irrigate more land and yields are increased. When drip and LEPA irrigation replace surface irrigation, the increase in the productivity of water is usually very large. Labor requirements are greatly reduced.

The history of rural electrification in the United States is described in order to encourage rural electrification in those countries that have high or increasing levels of malnutrition and poverty. The advantages of using electricity from renewable sources are clearly demonstrated. The known potential for increasing electrical energy from renewable resources is huge. The total potential has not yet been quantified and should be evaluated.

The use of topographic maps for selecting possible dam sites is illustrated. Digital elevation models may also be useful. They can be used for identifying possible transbasin water transfers from high rainfall areas to those that are water stressed.

There has been little effort to improve measurements and/or reporting of surface water flow. The World Water and Climate Atlas (available on the Internet) is briefly described. Use of the Atlas for estimating streamflow and for further research on relationships between a moisture adequacy index (MAI) and monthly values of streamflow are strongly recommended.

Key words: dams, rural electrification, sustainable development, poverty, water, irrigation

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INTRODUCTION

Nearly half of the world's population lives in poverty. Poverty has many aspects that relate to wellbeing. Water availability for various uses influences many of the development indicators. The United Nations (2003) describes nine conferences on food and/or water held starting in 1977. World Bank (2002) lists percent of population undernourished in 1996-98. The world average is 18 percent. For low income (40.6 % of the population) – 24 % are undernourished, and for middle income (44.5 % of the population) – 11 %. In 18 countries, more than 40 % of the population is undernourished. Twenty countries have negative economic growth and 15 countries have population growth exceeding the world's average economic growth.

There is little connection between annual renewable freshwater used for agriculture and malnutrition. Liberia has 49% malnutrition (2.7 times the world average and 8.6 times the world average annual renewable freshwater per capita. Excess water application has damaged 20 percent of the irrigated lands due to increased waterlogging and salinization. This has reduced income by more that $11 billion (Halweil, 2002).

Many developing countries are increasing the use of fossil fuels to produce electricity and promote industrialization. An increase in income makes it possible for the purchase of food grains. Appenzoller (2004) described the carbon cycle and concluded: "we don't have long to dither". A listing of related websites is at national geographic.com/magazine/0402

United Nations (2003) devotes a chapter describing a world water crisis. Assuming business as usual, there will be more serious and more frequent water crises. The purpose of this paper is to demonstrate that the management of water as a renewable resource is much more important than the annual renewable water supply or the amount used in agriculture.

The World Bank development reports, United Nations (2003), and Gleick (2000 and 2002) publish data on water supply. Water supply for food production depends on precipitation, surface water, and groundwater. The World Water and Climate Atlas (IWMI, 1999) provides a method for evaluating the precipitation potential. Data are not available on the safe yield of groundwater. Over exploitation is rapidly depleting the groundwater supply. Surface water or streamflow measurements are the least reliable and least available in the areas or regions where there is the greatest need for reliable data.

WATER, FERTILITY, AND FOOD PRODUCTION

Various publications indicate how water adequacy relates to potential crop yield. Hargreaves (1975) developed a relative yield equation. Hargreaves and Merkley (1998) present various interactions of water and fertilizers on crop yields. If rainfall is fairly adequate, fertilizers can sometimes double crop yields. When water is too limiting, fertilizers can reduce yields. The International Water Management Institute (IWMI, 1999) used the World Water and Climate Atlas to map monthly agricultural potential for South Asia. Monthly values of a moisture adequacy index (MAI) were used to indicate water adequacy. MAI is the 75 percent probable rainfall amount divided by reference evapotranspiration (ET_0). Values of monthly MAI were used with the relative crop yield equation.

Gleick (2000) shows a change in overall productivity of 13 crops from shifting to drip irrigation from commercial irrigation. The average increase is 146 percent. Drip irrigation required one tenth as much labor as surface irrigation. India and China have much more than 40 percent of the world's irrigated area and use drip irrigation on less than one percent of the irrigated area. The potential for increasing food production is enormous. Rural electrification is needed in order to increase water productivity and electricity can also be used to pump water from rivers, lakes, and canals. When hydropower is used, the storage required frequently provides a source of additional water for irrigation. Hargreaves and Merkley (2003) show the influence of the use of electricity on various development indicators for Latin America and the Caribbean. An increase in use of one-megawatt hour (MWh) increases gross national income (GNI) measured in purchasing power parity (PPP) dollars per capita by nearly four dollars. An increase in use also increases life expectancy and literacy. Poverty, Malnutrition, and population growth are decreased.

Some comparisons were made using data from six countries representing 44 percent of the world's population. The coefficients of determination were compared. The order of importance for the reduction of malnutrition was ranked. The ranking is as follows: 1) income expressed as GNI per capita; 2) the MWh per capita; 3) the amount of fertilizer used in kilograms per hectare of arable land; 4) the amount of freshwater withdrawn per capita for use in agriculture; 5) the hectares of irrigated land per capita; 6) the distribution of income within the country; and 7) the amount of arable land per capita.

Poverty and undernourishment were compared with water used for agriculture and with electrical power used. For the five countries using the most water Lao PDR is third in the amount of water used, has 26.9 % living on less than \$1.00 per day and 29.7 % of the population undernourished. For the five countries using the most electricity, there is not a significant amount of poverty or malnutrition. For the five most rural countries, Nepal had 34.9 % living on less than \$1.00 a day and 28 % undernourishment. Undernourishment varied from 29% to 68 %. Rwanda had 7.7 % living on less than \$1.00 a day. Poverty was not significant in the other countries. There was little neither significant poverty nor undernourishment in the countries that were the least rural. The amount of electricity used per capita has more influence on reducing malnutrition and poverty than the amount of freshwater per capita used in agriculture. Rural electrification can have a powerful influence on lifting people out of poverty and in reducing malnutrition.

THE RURAL ELECTRIFICATION ADMINISTRATION (REA)

Few acts of Congress, if any, have changed the economy more and the way people live more than REA. However, REA was made possible and productive as the result of the history of these times. Created by separate legislation during the Great Depression, the National Industrial Recovery Act (NIRA) of 1933 authorized the Public Works Administration (PWA). The PWA became the primary source of funding for the Bureau of Reclamation. More than half of the hydropower projects of the USBR came on line during the 1940s. There was an urgent need to find uses for the newly available electricity and an urgent need to use the electricity to promote economic recovery. Electricity was also an essential source of energy for a number of activities required by World War II industries in the United States.

The experience gained had a major impact on the economic recovery of Europe. Liberal assistance for hydropower development was provided under the Truman Doctrine (American Aid for Greece and Turkey) and by loans from the World Bank. In Greece, the economy quadrupled in 20 years (1948 – 1968) (Hargreaves 2003). Rural electrification had an important role contributing to rapid economic development of Greece. The availability of electricity and the large increase in irrigated areas in Brazil, resulting from dam construction, improved the economy and greatly improved the environment (Hargreaves, 2003).

The Bureau of Reclamation has supported sustainable global development. Technical assistance has been provided to more than 80 countries and training has been provided for more than 10,000 international leaders, engineers, and scientists.

INFLUENCE OF ENERGY ON THE ECONOMY

The gross national income (GNI) per capita in purchasing power parity (PPP) dollars for the world is 7410 (World Bank 2002). Nearly 3 billion people earn less than $2 a day and 2-3 billion people will be added in the next 30 – 50 years (World Bank, 2003). There should be a better distribution of income. However, suggestions for promoting a better distribution are not included in this paper.

World Bank (2002) provides a summary of various sources of energy. All forms of energy, including traditional, are converted in the World Bank tables to kilograms of oil equivalent (kgOE). Sources of electricity are, however, also shown separately. The economy is reported in purchasing power parity (PPP) dollars. The world average gross domestic product (GDP) is 4.4 dollars per kgOE. There is a significant difference between urban and rural areas in the effect on the economy from an increase in energy use.

Twenty-four countries, representing 74.5 percent of the world's population, were selected. Various linear regressions were made for gross national income (GNI) in purchasing power parity (PPP) dollars per capita on the Y-axis and kilowatt hours (KWh) on the X-axis. The slope of the equation is the first derivative and represents the per capita influence in PPP dollars of the increase of one KWh per capita.

An attempt was made to evaluate the relationship of various conditions on per capita increase in GNI from a per capita increase in one KWh. The 24 countries were divided into two groups, the 12 highest and the 12 lowest for each condition.

Table 1. Conditions that influence gross national income per capita (GNI)

Condition	**Equation**	r^2
Lowest GNI per capita	GNI = 1065 + 4.33 x KWh	0.83
Highest GNI per capita	GNI = 3783 + 2.97 x KWh	0.80
Lowest use of hydropower	GNI = 2514 + 3.14 x KWh	0.82
Highest use of hydropower[1]	GNI = 1306 + 3.71 x KWh	0.76
Lowest % or rural population	GNI = 4,487 + 2.93 x KWh	0.84
Highest % of rural population	GNI = 1062 + 4.02 x KWh	0.87
The 24 countries	GNI =1798 + 3.24 x KWh	0.90

[1]Eleven countries. One outlier was eliminated.

These seven equations in Table 1 demonstrate that gross national income (GNI) directly increases with the increase use of electricity and that rural low-income countries benefit most from an increase in the use of electricity. Countries with the most malnutrition were usually amongst those with the highest percentage rural, the lowest GNI, and the lowest use of electricity. Rural electrification can produce a large increase in food adequacy and a large decrease in world poverty.

OTHER INTERACTIONS WITH THE USE OF ENERGY

The quality of life is improved with increasing security, increased equity in the distribution of income and various other factors. Regression analyses indicate that when there is more use of energy, various other conditions are changed. There is more income per capita, less malnutrition, people live longer and are more literate. The rate of increase in the population is lower. The World Bank (2002) gives values of KWh and GNI per capita for most countries. Nine of the poorest countries use an average of 81.5 KWh per capita and have an average GNI per capita of 741($2 a day). As energy use increases, there is more demand for skilled labor and for education. When more electricity is used fertilizer use increases. Four development indicators that correlate best with and decrease malnutrition are: percentage of the rural population, gross national income, KWh of electricity and fertilizer use per capita. These indicators are listed in decreasing order of their coefficients of determination (r^2). These four indicators interact on each other. However, it is obvious that when little energy is used, poverty and malnutrition are high, life expectancy and literacy are low, and the population increases faster.

There is general agreement that poverty (below $2.00 a day); malnutrition in percent of the population and AIDS in percent of the population should be reduced to half of the present levels. World Bank (2002) and (2004) summarize various development indicators. The summaries include seven geographic regions and the low-income and middle-income portions of the world. AIDS is 3.79 times as prevalent in the low-income portion of the world than in the middle-income portion. The medium-income countries use 3.94 times as much electricity per capita as the low-income countries. However, when regressed with income or with the use of electricity, the coefficients of determination (r^2) are very low.

The seven regions, the world, Argentina, Uruguay, and the United States were regressed with the following r^2 values.

Regression	r^2
GNI as function of MWh per capita	0.92
GNI as function of fertilizer use per capita	0.87
GNI as function of arable land per capita	0.24
GNI as function of freshwater used in agriculture	0.05
Undernourishment as a function of GNI	0.67
Undernourishment as a function fertilizer used	0.56
Undernourishment as a function MWh per capita	0.51

Poverty and malnutrition can be reduced to meet the goals decided upon by increasing GNI per capita and/or increasing the use of electricity in MWh per capita. AIDS decreases as income increases but the low regional correlations are difficult to explain. The ratio of female to male enrollment in primary and secondary education for the low-income countries is 78 percent but is 98 percent in medium-income countries. Increases in income, use of electricity, and an increase in the education of women all interact to substantially decrease the incidence of AIDS.

BENEFITS OF HYDROPOWER

Due to lower generating or operating costs, hydropower produces more benefits than does the use of fossil fuels without the production of CO_2 emissions. The 12 countries (with 17 percent of the world's population) using the most hydropower had emissions averaging 2.71 tons of CO_2 per capita. This is significantly less than the 4.09 tons of CO_2 per capita for the 12 countries using the least hydropower. Electrical production should be rapidly increased but the emphasis should be on renewable sources of energy. The use of coal to produce a megawatt hour (MWh) of electricity also produces one ton of carbon dioxide emissions (United Nations 2003).

Although, Aqua-Media International, Ltd. (1997) indicates that about 27 percent of the world's potential hydropower has been developed, the potential is much greater. There are many areas that have not been evaluated. An inventory of the hydropower potential should include low-head and run-of-the river sites. These sites will require the relocation of relatively few people, enhance food production and have little impact on flood recession agriculture. The costs and difficulty of alleviating adverse impacts needs to be evaluated (See WCD, 2000).

Asia is projected to provide the largest future demand for energy. China and Japan are the two greatest sources of trade with the United States. India is a major producer of the world's software. There will be a significant increase in the use and demand for energy in these countries. Fortunately, in 1997, there were many large-scale dams of 60 meters or more height under construction in Asia. Those with hydropower included were: China – 64, India – 12, Iran –21, Japan – 23, and Turkey – 17 (Aqua Media International, 1997). These countries are 68, 72, 38, 21, and 21 percent rural, respectively (World Bank, 2002). Rural electrification can and undoubtedly will have a large impact on the economies of these countries. If the United States and other developed nations promote rural electrification in the world, it will increase world trade and prosperity.

Grid electricity is and will be an essential factor in increasing income and lifting people out of poverty (United Nations, UNESCO, 2003). Back to back, AC/DC high voltage transmission makes the interconnection of the grids of each continent feasible. With the interconnection of the grids, the various countries can benefit by freely trading the power produced. The interconnection of electrical grids can also be an important step towards true globalization and improved security. Ninety five percent of the US military interventions of the last 20 years have occurred in countries disconnected from globalization (Barnett and Gaffney, 2003).

SELECTING DAM SITES

Digital elevation models (DEM) are available on the Internet at various spatial coverages. The values from a DEM may be useful in selecting dam sites and in identifying topography that will permit transbasin transfers from high rainfall areas to those with low rainfall. All towns, villages, roads, institutions and services affected by the reservoirs should be compiled from maps and census data. Preliminary selection should make use of the monthly rainfall amounts available from records or estimated from the "World Water and Climate Atlas".

South America (with areas of high rainfall, large elevation differences, and large rivers) has many good sites for hydropower development. Those sites with the greatest benefits and the least negative impacts should be selected for further study. However, streamflow data are frequently not adequate for evaluating the potential hydropower production.

The Canadian International Development Agency (CIDA) sponsored a study of potential hydropower sites in Honduras. The 1:50,000 topographic maps were used to identify 62 potential sites. Of these, 16 sites were selected for possible inclusion in a generation plan. These sites would displace only a few people. The reservoirs would enhance fish production. There would be a reduction in fossil fuel use. The principal environmental impacts anticipated would be a large reduction in slash and burn agriculture practices. Currently, annual fires are started to provide food and employment for the rural poor. The smoke form these fires is sometimes so intense that airline traffic is suspended for days. Without the smoke, there would be a significant decrease in air pollution and health damage. Development at the 16 sites would approximately double the Honduran electrical generating capacity indicated by Aqua-Media International, Ltd (1997).

Some transbasin water diversions are suggested for evaluation sponsored by international development agencies. These include: 1) use of dams in Bolivia to irrigate land in Peru, Bolivia, Paraguay, and Argentina; 2) possible diversion of water from the Congo River to the White Nile; 3) diversion of water from rivers in Alaska and Canada to irrigate lands in Western Canada, The United States, and Mexico.

"WORLD WATER AND CLIMATE ATLAS"

The "World Water and Climate Atlas" was jointly developed by the International Water Management Institute (IWMI) and the Utah Climate Center at Utah State University. This atlas can be accessed at www.cgiar.org/iwmi or www.iwmi.org. It provides annual, monthly, and 10-day summaries normalized for the period 1961-90. The precipitation parameters are: total precipitation (P), the 75% precipitation probability (P_{75}), number of days with precipitation (DWP), and Standard Deviation (SD). The agricultural parameters are: reference evapotranspiration (ETo), moisture adequacy index (MAI= P_{75}/ETo), and net crop moisture (NET = ETo - P_{75}). IWMI has recently received funding to expand the Atlas with a number of data layers. The expanded Atlas will probably include some information on groundwater and surface water. IWMI has a PhD program to support research related to use of the Atlas. Information regarding the program is available at http://www.cgiar.org/about/capacity-building/phd-scholarship.htm

ESTIMATING STREAMFLOW

Streamflow measurements are frequently scarce, fragmentary, incomplete, and of questionable reliability. In many developing countries, flood flows are not measured or even estimated. There is a need for much review and evaluation of data and for research on ways to estimate streamflow from climate data where necessary. The 75% probable amount (Q_{75}) of streamflow has been used for planning and design of water resource development. Q_{75} can be calculated from the following equation:

$$Q_{75} = Q_m - 0.74 \times SD \qquad (1)$$

where Q_{75} is the 75% probable runoff, Q_m is the mean flow, and SD is the standard deviation.

The IWMI "World Water and Climate Atlas" provides the necessary variables to estimate streamflow: reference crop evapotranspiration (ET_0), and the 75 percent probable rainfall amounts (P_{75}), a moisture adequacy index (MAI), and net evapotranspiration (NET). Monthly values of P_{75} - ET_0 (negative values of NET recorded as positive) for those months for which P_{75} exceeds ET_0 can be summed and recorded as S. Good correlations between annual values of Q_{75} and S can be found.

Rainfall does not all runoff the day it falls – much of it infiltrates into the soil where it is temporarily stored. Good correlations between MAI and Q_{75} have been found when an offset of 15 days has been used (a 15-day delay). The resulting equation in the form of $Q_{75} = A + B \times MAI$ can be used to estimate values of Q_{75} for similar watersheds. Hargreaves and Olsen (1999) used data from several watersheds in Honduras to compare Q_{75} with a 15-day lag time (Q_{75L}) with monthly values of MAI. The resulting equation with $r^2 = 0.93$ was:

$$Q_{75L} = 3.2 + 14.78\ MAI \qquad (2)$$

in which Q_{75L} was in liters per second per square kilometer (l/s/km^2). Values of A are usually approximately equal to base flow. From other regressions, values of B have been as low as 12.0. Significantly more research is recommended on these relationships. However, for design purposes, it is simpler to disregard the delay.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Rural electrification was a powerful influence in mitigating and ending the Great Depression and it has been proven of value in many other countries. Use of hydropower is more profitable than the use of fossil fuels. Carbon dioxide emissions from coal and other fossil fuels are creating a global environmental problem. There is a need to inventory the world's resources for the production of clean renewable energy. It is strongly recommended that an inventory be made of sites for low dams, high dams, and run-of-the-river hydropower production be developed. The potential for hydropower had not been evaluated. In Honduras, 46 sites have been identified but not evaluated. Many sites in other countries cannot be evaluated until more surface water flow data becomes available. In order to evaluate the potential for hydropower, it is necessary to know how much and when water will be available. It is strongly recommended that the international agencies join in providing support to expand the "World Water and Climate Atlas" to include streamflow data.

There is considerable urgency in promoting hydropower development. Eighteen percent of the world's population has not enough to eat and 20 countries have negative economic growth. Fifteen countries have population growth exceeding the world's average economic growth. Many have enough but most have too little. When too many have too little, there is the possibility that they may be willing to fight in order to obtain more. A world food forum is useful but the real need is action. It is recommended that the World Bank, the United Nations, and other international development organizations promote rural electrification from renewable sources of energy to improve the economy, reduce CO_2 emissions, and improve the global environment and security. Business as usual will result in crisis of food production and carbon dioxide emissions. Good management of renewable resources can prevent these crises. The world does not have long to dither.

The road from Rio to Johannesburg has been paved with food and water conferences. A conference on how to develop and promote rural electrification by using renewable and sustainable energy could solve some of the problems associated with poverty and malnutrition.

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HIERARCHICAL BAYESIAN ANALYSIS AND STATISTICAL LEARNING THEORY I: THEORETICAL CONCEPTS

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ABSTRACT

This manuscript presents examples of state-of-the-art techniques for forecasting that combine excellent generalization properties and sparse representation within a Bayesian paradigm. A relevance vector machine (RVM), which is a probabilistic model, has been used in an on-line fashion to provide confident forecasts given knowledge of some state and exogenous conditions. In practical applications, on-line algorithms should recognize changes in the input space and account for non-stationarity (or "concept drift", or simply "drift") in system behavior. Support vectors machines (SVMs) lend themselves particularly well to detection of such changes and consequently adapt to a recognized shift in system structure. The resulting model will normally have a structure and parameterization that suits the information content of the available data.

INTRODUCTION

Water has been harnessed for millennia in support of the achievement of social goals. Nevertheless, it is evident that many efforts to utilize water have been inadequate (NRC, 2001). In the future, moreover, available water resources will be subjected to greater pressure in the face of increasing demands. Thus, there is growing recognition of the need to more intensively manage water in order to achieve an increasing diverse set of water-related social goals (Postel et al., 1996; Gleik, 1993). Therefore, successful management of river basins will require more systematic, comprehensive, and coordinated approaches that will need more--and better quality--information about the state of the water resources systems we manage.

Conceptual or physically based models are of importance in the understanding of hydrologic processes and can be implemented to address these water resources information needs. Water resources problems are often not clearly understood or are too ill defined for a meaningful analysis using physically based modeling methods. Moreover, physically based models are sometimes limited by the multitude and complexity of the processes involved and by the paucity of data.

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Recent decades have seen a growing interest in research in data driven modeling and development of intelligent systems. Intelligent systems might be made to evolve reliable models using measured historical data. Such models should be able to capture, or "learn", the behavior of the underlying physical processes and lend themselves to real-time water systems operation problems. Learning machines are characterized by their fundamental ability to deduce models of system behavior from measured data. Without sacrificing accuracy, they might provide a potentially valuable method for reducing the cost of data collection and modeling of complex river basin systems in support of water management (Velickov and Solomatine, 2000). However, the lack of stationarity and poor sampling of persistent phenomena diminish the value of empirical records. Consequently, effective modeling of any dynamic behavior will require an adaptive paradigm. The required adaptive nature of the model is treated here as an integral dimension of a fully automated decision support system. This is done to underscore the fact that effective forecasting of basin dynamic behavior will have to be able to detect non-stationarity, or "concept drift", and account for new trends in that behavior. We argue that such a scheme for model formulation might present an appropriate foundation for the practical study of water resources system non-stationarity and for the management of large water systems that are subject to significant uncertainty in their behavior.

The objective of this paper is to provide a statistical paradigm that has the ability to recognize drift and evolve, when it is needed, a new forecasting machine. A Bayesian extension of learning machines allows the characterization of uncertainties in both the model parameters and the data. The framework provided in this paper utilizes an efficient learning machine, called a relevance vector machine (RVM), that embodies these capabilities. The paradigm formulated here emerges from an inductive modeling procedure where the model structure is identified parsimoniously. This should have wide application potential in water resources modeling and management. The complexity of the model and the resulting model structure will have a parameterization that is appropriate for the information content. It is also self-adaptive and able to identify and reflect new characteristics of the system, which, in a broader sense, might be interpreted in physically or operationally meaningful contexts.

MODEL DESCRIPTION

Background

Given a set of examples of input vectors $\mathbf{x}_n$ where $n \in (1, \cdots N)$ and its corresponding outputs, or targets, $\mathbf{t}_n$, where $D \sim \{(\mathbf{x}_n, \mathbf{t}_n) \rightarrow \mathrm{R}^d \times \mathrm{R},\ \mathrm{n}=1,\ \cdots,\ \mathrm{N}\}$ is the training dataset, one wishes to learn from this set a model of dependency of the targets on the inputs with the objective of using the model to make accurate predictions of $\mathbf{t}$ for previously unseen values of $\mathbf{x}$. Learning algorithms provide a function, $y(\mathbf{x})$, that is "learned" over the input space. The learning process involves inferring the parameters of the function from D. Commonly, $y(\mathbf{x})$ takes the form:

$$y(\mathbf{x};\mathbf{w}) = \sum_{i=1}^{M} w_i \Phi_i(\mathbf{x}) = \mathbf{w}^T \boldsymbol{\Phi}(\mathbf{x}), \tag{1}$$

in which the output is a linearly weighted sum of M nonlinear basis functions, $\boldsymbol{\Phi}(\mathbf{x})$. The "learning" process produces estimates of the proper values for the weights, $\mathbf{w}$. Tipping (2000) has detailed a Bayesian probabilistic approach for learning models of this form. The key features of this approach are good generalization accuracy and a sparse formulation (Tipping, 2000, 2001). The form of the function, $y(\mathbf{x})$, adopted in Tipping (2000) corresponds to that of support vector machines (SVMs) in the sense that it is sparse and linearly parameterized (Vapnik, 1995; Vapnik 1998). Due to the similarity of its functional form to SVMs, Tipping (2000) calls it the "relevance vector machine" (RVM). RVMs are inspired by the concept of automatic relevance determination (ARD) (MacKay, 1994; Neal, 1994). ARD is implemented in problems where there are many input variables, some of which are actually irrelevant to the prediction of the output variables. The sparse Bayesian learning (SBL) framework depicted in ARD, and hence in RVMs, is based on a combination of likelihood and prior knowledge. Likelihood describes the underlying processes in the training data. Prior models should be utilized to handle the model complexity and as a result, to enable generalization to non-training data (Suykens et al., 2003). So, RVMs are characterized by a highly effective mechanism for avoiding over-fitting, which results in good generalization. Exceptionally good results have been reported on many tasks where RVMs have been applied (Dibike et al., 2001). RVMs have demonstrated superior performance over standard learning machines (e.g., artificial neural network), *remarkably in regression*, since they were introduced by Tipping (2000). The most advantageous feature of RVMs is that they yield a very sparse representation in terms of kernel functions (Tipping and Faul, 2002; Tipping, 2001; Tipping, 2000).

Relevance Vector Machines

Specifically, the model presented here has the following formulation, which uses the common notation introduced by Tipping (2000; 2001):

$$t_n = y(\mathbf{x}_n, \mathbf{w}) + \varepsilon_n, \tag{2}$$

where $\varepsilon_n \sim \mathcal{N}(0, \sigma^2)$. Thus, $p(t_n \mid \mathbf{x}) = \mathcal{N}(t_n \mid y(\mathbf{x}_n), \sigma^2)$. In words, t_n has a Gaussian distribution with mean $y(\mathbf{x}_n)$ and variance σ^2, and the noise, ε_n, has a Gaussian distribution with zero mean and σ^2 variance. The function $y(\mathbf{x};\mathbf{w})$ depicted in Equation (1), is identified by basis functions with kernels parameterized over the training inputs: $\Phi_i(\mathbf{x}) \equiv K(\mathbf{x},\mathbf{x}_i)$. The likelihood of the complete data set can be written as:

$$p(\mathbf{t} \mid \mathbf{w},\sigma^2) = (2\pi\sigma^2)^{-N/2} \exp\left\{-\frac{1}{2\sigma^2}\left\| \mathbf{t} - \mathbf{\Phi w} \right\|^2\right\}, \tag{3}$$

where $\mathbf{t} = [t_1 \; ... \; t_N]^T$ are identically and independently distributed (iid), $\mathbf{w} = [w_o \; ... \; w_N]^T$, and, $\mathbf{\Phi}(\mathbf{x}_n) = [1, K(x_n, x_1), K(x_n, x_2), \cdots, K(x_n, x_N)]^T$. Without imposing the hyperparameters on the weights, $\mathbf{w}$, the maximum likelihood of Equation (3) will suffer from severe overfitting. Therefore, imposing some additional constraint on the parameters, $\mathbf{w}$, by adding a complexity penalty to the likelihood or the error function is recommended. A way to constrain the weights is to parameterize them with higher-level hyperparameters so as to produce a smooth (or less complex) function. Tipping (2000) proposed an explicit zero-mean Gaussian prior probability distribution over the weights, $\mathbf{w}$:

$$p(\mathbf{w} \mid \boldsymbol{\alpha}) = \prod_{i=0}^{N} \mathcal{N}(w_i \mid 0, \alpha_i^{-1}). \tag{4}$$

with $\boldsymbol{\alpha}$ a vector of $N+1$ hyperparameters associated independently with every weight. The *a priori* information controls the generalization ability of a learning system. The assignment of a hyperparameter to each weight, and accordingly to each basis function, is the key feature that is responsible for the sparse representation of the machine. Hyperpriors over $\boldsymbol{\alpha}$, and the noise variance σ^2, have to be defined to complete the specification of the hierarchical prior.

A plausible guess for a conjugate family of prior distributions is the class of gamma distributions. So the evidence of the data will allow the posterior probability distribution to concentrate at very large values of $\boldsymbol{\alpha}$. The posterior probability of the associated weight will be concentrated at zero. Therefore one could deem the corresponding inputs irrelevant (Tipping, 2001). Relevant vectors (RVs) tend to represent a prototypical structure (Li et al., 2002).

Using Bayes' rule, for the purpose of attaining optimal hyperparameters, the posterior over all unknowns could be computed given the defined non-informative prior distributions:

$$p(\mathbf{w},\boldsymbol{\alpha},\sigma^2 \mid \mathbf{t}) = \frac{p(t \mid \mathbf{w},\boldsymbol{\alpha},\sigma^2).p(\mathbf{w},\boldsymbol{\alpha},\sigma)}{p(\mathbf{t})} \tag{5}$$

Then, for new observations the predictive distribution used to produce predictions is:

$$p(t_{N+1} \mid \mathbf{t}) = \int p(t_{N+1} \mid \mathbf{w},\boldsymbol{\alpha},\sigma^2) p(\mathbf{w},\boldsymbol{\alpha},\sigma^2 \mid \mathbf{t})\, d\mathbf{w}\, d\boldsymbol{\alpha}\, d\sigma^2 \tag{6}$$

where t_{N+1} is the corresponding target of a new test point, $\mathbf{x}_{N+1}$. Decomposing the posterior would facilitate the solution:

$$p(\mathbf{w},\boldsymbol{\alpha},\sigma^2 \mid \mathbf{t}) = p(\mathbf{w} \mid \mathbf{t},\boldsymbol{\alpha},\sigma^2)p(\boldsymbol{\alpha},\sigma^2 \mid \mathbf{t}) \tag{7}$$

The posterior distribution of the weights is:

$$\begin{aligned} p(\mathbf{w} \mid \mathbf{t},\boldsymbol{\alpha},\sigma^2) &= \frac{p(\mathbf{t} \mid \mathbf{w},\sigma^2).p(\mathbf{w} \mid \boldsymbol{\alpha})}{p(\mathbf{t} \mid \boldsymbol{\alpha},\sigma^2)} \\ &= (2\pi)^{-(N+1)/2}|\boldsymbol{\Sigma}|^{1/2} \exp\left\{-\frac{1}{2}(\mathbf{w}-\boldsymbol{\mu})^T\boldsymbol{\Sigma}^{-1}(\mathbf{w}-\boldsymbol{\mu})\right\} \end{aligned} \tag{8}$$

where the posterior covariance and mean are respectively:

$\boldsymbol{\Sigma} = (\sigma\boldsymbol{\Phi}^T\boldsymbol{\Phi} + \mathbf{A})^{-1}$,with $\mathbf{A} = diag(\alpha_1,\alpha_2,\cdots,\alpha_{N+1})$, and $\boldsymbol{\mu} = \boldsymbol{\Sigma}\boldsymbol{\Phi}^T\sigma^{-2}\mathbf{I}_N\mathbf{t}$ where $\mathbf{I}_N$ is the identity matrix. Tipping (2000, 2001) proposed to approximate the hyperparameter posterior $p(\boldsymbol{\alpha},\sigma^2 \mid \mathbf{t})$ by a very effective delta function at its most probable values $\boldsymbol{\alpha}_{MP},\sigma^2_{MP}$. Then:

$$\int p(t_{N+1} \mid \boldsymbol{\alpha},\sigma)\delta(\boldsymbol{\alpha}_{MP},\sigma_{MP})d\boldsymbol{\alpha}d\sigma^2 \approx \int p(t_{N+1} \mid \boldsymbol{\alpha},\sigma)p(\boldsymbol{\alpha},\sigma \mid \mathbf{t})\,d\boldsymbol{\alpha}\,d\sigma^2 \tag{9}$$

As a consequence, learning becomes a search for hyperparameter posterior most probable, i.e., the maximization of $p(\boldsymbol{\alpha},\sigma^2 \mid \mathbf{t}) \propto p(\mathbf{t} \mid \boldsymbol{\alpha},\sigma^2)p(\boldsymbol{\alpha})p(\sigma^2)$ with respect to $\boldsymbol{\alpha}$ and β. Given uniform hyperpriors, Tipping (2000) concludes that one needs only to maximize the term $p(\mathbf{t} \mid \boldsymbol{\alpha},\sigma^2)$:

$$\begin{aligned} p(\mathbf{t} \mid \boldsymbol{\alpha},\sigma^2) &= \int p(\mathbf{t} \mid \mathbf{w},\sigma^2)p(\mathbf{w} \mid \boldsymbol{\alpha})\,d\mathbf{w} \\ &= \left((2\pi)^{-N/2}\Big/\sqrt{\left|\sigma^2\mathbf{I} + \boldsymbol{\Phi}\mathbf{A}^{-1}\boldsymbol{\Phi}^T\right|}\right)\exp\left\{-\frac{1}{2}\mathbf{t}^T(\sigma\mathbf{I} + \boldsymbol{\Phi}\mathbf{A}^{-1}\boldsymbol{\Phi}^T)^{-1}\mathbf{t}\right\} \end{aligned} \tag{10}$$

In related Bayesian models, this quantity is known as the marginal likelihood, and its maximization is known as *the type II-maximum likelihood* method or "evidence for hyperparameter". Its maximization is the "evidence procedure" (Berger, 1985; Wahba, 1985; MacKay, 1992). Hyperparameter estimation is conducted with an iterative formulae. For $\boldsymbol{\alpha}$, differentiation of $p(\mathbf{t} \mid \boldsymbol{\alpha},\sigma^2)$ and equating to zero will produce the result (MacKay, 1992). The predictive distribution for a new query $\mathbf{x}_{N+1}$ becomes:

$$p(t_{N+1} \mid \mathbf{t},\boldsymbol{\alpha}_{MP},\sigma^2_{MP}) = \int p(t_{N+1} \mid \mathbf{w},\sigma^2_{MP})p(\mathbf{w} \mid \mathbf{t},\boldsymbol{\alpha}_{MP},\sigma^2_{MP})\,d\mathbf{w}, \tag{11}$$

which is readily computed, giving :

$$p(t_{N+1} \mid \mathbf{t}, \boldsymbol{\alpha}_{MP}, \sigma_{MP}^2) \sim \mathcal{N}(t_{N+1} \mid y_{N+1}, \sigma_{N+1}^2), \tag{12}$$

with, $y_{N+1} = \boldsymbol{\mu}^T \boldsymbol{\Phi}(\mathbf{x}_{N+1})$, and $\sigma_{N+1}^2 = \sigma_{MP}^2 + \boldsymbol{\Phi}(\mathbf{x}_{N+1})^T \boldsymbol{\Sigma} \boldsymbol{\Phi}(\mathbf{x}_{N+1})$.

In summary, the RVM introduces a prior over the weights, $\mathbf{w}$, governed by a set of hyperparameters, one associated with each weight (prior assumptions' parameters are commonly called hyperparameters). The most probable values of the hyperparameters are iteratively estimated from the data (Tipping, 2000; 2001). A sparse representation is obtained by the tendency for many weights to have zero values, and the posterior distribution of the corresponding hyperparameters will become infinitely peaked about zero. The associated training vectors are irrelevant and ought to be pruned, while the remaining are relevant vectors; thus the algorithm summarizes the data space concisely (Tipping, 2001;Wipf et al., 2004).

Model Selection

One reason for seeking a solution using a Bayesian approach is the fact that parameters are data evident, yet parameters within the kernel specification ought to be adapted to improve the marginal likelihood (Quinonero-Candela and Hansen, 2002). Therefore, to obtain an optimal level of performance, a considerable number of design choices with respect to the RVM kernel must be done manually. Both the kernel type and the kernel parameters are influential in defining the design matrix $\boldsymbol{\Phi}$ and in specifying the tradeoff between training accuracy and model complexity (Figure 1). This tradeoff is a nontrivial aspect of model development, as illustrated in Figure 1. In general, a more complex machine will learn a training set better than a simpler one due to its higher flexibility (overfitting, Figure 1, d-e); however the simpler model may actually be better in the sense that it generalizes better in case of new inputs.

Cross validation techniques have been used for the purpose of exploring the tradeoff between model complexity and performance. However, they are expensive in terms of computation and data (Law and Kwok, 2001). The Bayesian framework has been proposed to address these issues, but its application presents considerable difficulties and is prohibitively slow (MacKay, 1992; Tipping, 2001). However, Bayesian approaches present a notable benefit if one considers the case of multiple input scale parameters, in which traditional cross validation is not an option, and performance gains may be achieved (Tipping, 2001).

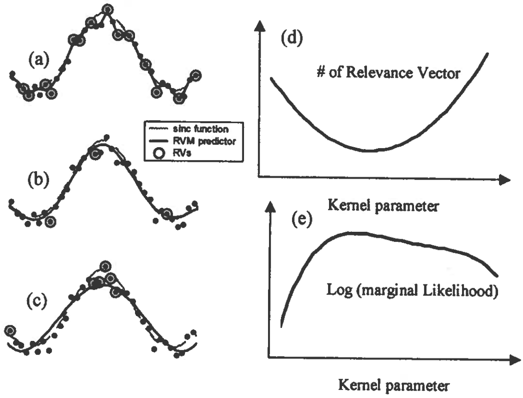

Figure 1: Optimization of model complexity. Graphics in a-c show interpolation of y =*sinc (x)* at different Gaussian parameters; d and e show the number of relevance vectors and marginal likelihood, respectively, as a function of kernel parameter

Accordingly, the basis function for input $\mathbf{x} \in \mathcal{R}^d$ with its corresponding scale parameters, $\boldsymbol{\eta} = (\eta_1, \ldots, \eta_d)$, will take the form:

$$\boldsymbol{\Phi}_m(\mathbf{x}) = \Phi_m(\sqrt{\eta}_1 x_1, \sqrt{\eta}_2 x_2, \ldots, \sqrt{\eta}_d x_d) \quad \textbf{(13)}$$

The objective of model selection is to find the optimal kernel parameter set. Tipping (2001) has shed some light on why it is important to select a model with respect to the input space kernel parameter, $\boldsymbol{\eta}$: a very narrow kernel width results in a diagonal covariance (not revealing any structure at all in the data), while a large width implies isotropic noise (Williams, 1999). "Occam's razor" is used as the principle for finding an optimal trade-off between fitting data and model complexity (MacKay, 1995; MacKay, 2003). Particularly, the approach adopted for this level of inference is to rank different models by $p(\mathcal{H}\,|\mathcal{D})$, where $\mathcal{H}$ define the space of all possible states of nature for the model (e.g., kernel parameters, $\boldsymbol{\eta}$).

Owing to the assumption of non-informative prior probabilities, $p(\mathcal{H})$, for all models, different models are compared and ranked according to the maximal evidence $p(\mathcal{D}\,|\mathcal{H})$ while assuming a Gaussian approximation for $p(\mathcal{D}\,|\boldsymbol{\alpha}_{MP}, \sigma^2_{MP}, \mathcal{H})$ at $\boldsymbol{\alpha}_{MP}$ and σ^2_{MP} (Suykens et al., 2002; Van Gestel et al., 2001). So, to find the optimal set of kernel width, $\boldsymbol{\eta}$, one maximizes the log of the marginal likelihood Equation (10) and the priors over $\boldsymbol{\alpha}$ and σ^2 which embody the concept of Occam's razor (MacKay, 2002).

$$p(\mathcal{D}\,|\boldsymbol{\alpha}_{MP}, \sigma^2_{MP}, \mathcal{H}) = \log p(\mathbf{t}\mid \boldsymbol{\alpha}, \beta, \boldsymbol{\eta}) + \sum_{i=1}^{N} \log p(\alpha_i) + \log p(\beta)\,, \tag{14}$$

Since there is no definitive method for optimizing $\boldsymbol{\eta}$, a better mechanism for doing so has been adopted in this manuscript by maximizing the marginal likelihood using the recently developed global optimization algorithm, adaptive simulated annealing (ASA). It is not the objective of this paper to explain different optimization algorithms. The motivation to use this optimization technique is illustrated in the results of Ingber and Rosen (1992), where they concluded that ASA strongly outperformed genetic algorithms (GAs) on a set of standard benchmark optimization testing functions. The ASA algorithm was developed by Ingber (1993; 1989) to overcome limitations of simulated annealing (SA) for multidimensional optimization problems.

NOVELTY DETECTION

The ability to create a self-organizing machine is a potentially useful tool for adaptive management of river basins. Such machines that can adapt and deal with dynamic input distributions, or, in other words, are able to detect concept drift. This paper provides a way for the machine-learning algorithm to perform updating whenever its current state does not forecast accurately. This is of paramount importance particularly when we consider dynamic data sets. The novelty (abnormality) detection used for condition monitoring and fault diagnosis will provide insightful information to the decision maker about new trends in the incoming data. Intuitively, the approach to this problem is to estimate a real-valued function for the distribution that underlies the data. A widely advocated approach is to create a binary-valued function that is unity in the domain of the training data set (i.e., in region where the probability density is greater than an arbitrary value) and zero elsewhere (Scholkopf et. al., 2001a, 2001b; Scholkopf et. al., 2000). The next section presents the use of statistical learning theory, and more specifically, support vector machines (SVMs), to define the algorithm so as to function as an on-line method and hence to capture regions in input space where the probability density lives (Vapnik, 1995; Scholkopf et. al., 2000; Blum, 1996). Again, a natural variation of the input space scenarios is strongly relevant to practice. Consequently, the target function ought not to be static, but instead should change with time (Blum, 1996). A well-equipped model that seeks a representation of the data set such that the target class is optimally clustered and easily distinguished as best as possible from the outlier class, will explain new trends to our machine (Tax et al., 1999; Tax and Duin, 1999). Most of the previous work to approach this dilemma is characterized with a theoretical slant and does not devise a functional algorithm that works on a high dimensional real-world problem. It is here where use of support vector machines--which have received great attention and have been extensively used for pattern recognition, regression estimation, and solution of inverse problems (Scholkopf et al., 2001b)--can be effectively applied.

Given a set of examples of input vectors $\{\mathbf{x}_n\}_{n=1}^{N}$, where $\mathbf{x} \in \mathcal{R}^d$, let $\ddot{\Phi}$ be a feature map $\mathbf{x} \to \mathrm{F}$, i.e., a map into inner product space F (Hilbert Space) where the inner product in the image of $\ddot{\Phi}$ can be computed by evaluating some kernel (Boser et al. 1992; Vapnik, 1995; Scholkopf et al., 1999). In the projected feature space the data lie on the surface of a hyper-sphere, and the strategy is therefore to separate this region by constructing a hyperplane that is maximally distant from the origin with all data points lying on the opposite side from the origin. The returned function, f, will take the value $+1$ in a small region containing the set of data points, and -1 or 0 elsewhere (Scholkopf et al., 2001b). Given a data set that has a probability distribution P in the feature space, the probability that a new input vector drawn from P lies outside the subset of the feature space, S (where all the inputs lie), is bounded by some *a priori* specified value $\nu \in (0,1)$. This geometric picture corresponds to:

$$\begin{bmatrix} \min\limits_{w,\xi,\rho} & J_P(w,\xi) = \frac{1}{2}w^T w + \frac{1}{\nu N}\sum_n \xi_n - \rho \\ \textit{Subject to} & \forall_{n=1}^{N} : (w^T \ddot{\Phi}(x_n)) \geq \rho - \xi_n, \quad \xi_n \geq 0 \end{bmatrix} \tag{15}$$

where ν is the tradeoff term between maximizing the distance from the origin and containing most of the training data in the region created by the hyperplane. It also corresponds to the percent of outliers in the training data set. ξ_n are the non-zero slack variables that allow for the possibility of examples violating the decision boundary, and ρ is a margin parameter. The objective function in Equation (15) penalizes both the classifier capacity through minimizing the regularization term $w^T w$, and the sum of the slacks $\sum_n \xi_n$. The Lagrangian form of Equation (15) is:

$$\begin{aligned} L(w,\xi,\rho,\alpha,\beta) = {} & \frac{1}{2}\|w\|^2 + \frac{1}{\nu N}\sum_n \xi_n - \rho - \\ & \sum_n (\alpha_n((w.\ddot{\Phi}(\mathbf{x}_n)) - \rho + \xi_n) - \beta_n \xi_n) \end{aligned} \tag{16}$$

where α_n and β_n are the Lagrange multipliers. After applying the optimality conditions on Equation (16), one obtains the dual problem:

$$\min_{\alpha} \quad \frac{1}{2}\sum_{nj} \alpha_n \alpha_j k(\mathbf{x}_n, \mathbf{x}_j) \quad \textit{Subject to} \quad 0 \leq \alpha_n \leq \frac{1}{\nu N}, \ \sum_n \alpha_n = 1 \tag{17}$$

The resulting decision function will be positive for most of the examples in the training set, and negative for novel or outlier data:

$$f(\mathbf{x}) = sign\left(\sum_j \alpha_j k(\mathbf{x}, \mathbf{x}_j) - \rho\right) \quad and \quad \rho = \sum_j \alpha_j k(\mathbf{x}_k, \mathbf{x}_j) \tag{18}$$

The optimization can be formulated as a quadratic program (QP) and hence can be readily solved.

In summary, the SVM serves to map the input vector to a high dimensional feature space and construct an optimal separating hyper-plane through structural risk minimization. The examples, which define the optimal hyper-plane, are called support vectors and they are the only subset stored for doing future classification.

The second part of the manuscript will present an application of the paradigm formulated in here, which illustrates the use of this framework in real-time management of water resources.

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HIERARCHICAL BAYESIAN ANALYSIS AND STATISTICAL LEARNING THEORY II: WATER MANAGEMENT APPLICATION

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Mac McKee‡

ABSTRACT

Water scarcity and uncertainties in forecasting future water availabilities present serious problems for basin-scale water management. These problems create a need to design intelligent prediction models that learn and adapt to their environment in order to provide water managers with decision-relevant information related to the operation of river systems. State-of-the-art techniques fused into a model paradigm (described in Part I of this manuscript) will be demonstrated as decision tools to enhance real-time water management. The framework previously discussed in Part I will be able to diagnose abnormality in the system. Abnormality in this context is referred to as outliers, false signals (e.g., the result of sensor failure) and system behavior "drift" (i.e., non-stationarity or "concept drift"). The proposed versatile adaptive paradigm might be utilized in any control process of a dynamical system in which a quantitative characterization of uncertainty is required. The utility and practicality of this proposed approach is demonstrated here with an application in a real case study river basin.

APPLICATION FOR REAL TIME MANAGEMENT

Description of the Study Area

The Sevier River Basin in rural south-central Utah is one of the state's major drainages. A closed river basin, it encompasses 12.5 percent of the state's total area. From the headwaters 250 miles south of Salt Lake City, the river flows north and then west 255 miles before reaching Sevier Lake (Berger et al., 2002). Irrigation is the primary use of water in the basin. The average amount of water diverted annually for cropland irrigation is 903,500 acre-feet. Of this amount, approximately 135,000 acre-feet are pumped from groundwater. About 40 percent of the diversions are return flows from upstream use (Berger et al., 2002). (For a detailed description of the basin and much of the real-time database utilized in this research, refer to http://www.sevierriver.org).

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Effective real-time management of the water of the Sevier River Basin is seen by the managers of the irrigation systems in the basin to be extremely important in achieving an optimal allocation of their scarce water resources. The main functions of an integrated real-time water resources management system are: water resources real-time monitoring and data collection, information and knowledge mining, and prediction for real-time decision support. Real-time water resources management requires a heavily instrumented basin to monitor climatic indices, streamflow, and water demands. The Sevier River is a heavily instrumented basin of gauges that provide real-time data on all these variables. It is therefore a suitable study area to test tools that are not physically based, but that "let the data speak". These tools will ultimately be integrated into a water resources information management system to be used by the operators of the Sevier River water systems, especially in terms of prediction tools to help manage irrigation canal diversions and reservoir releases.

In physically based models, the necessary climatic, hydrologic, and hydraulic processes must be represented to provide near real-time forecasts of river and canal flows and, ultimately, required reservoir releases. Such models need a substantial amount of data that are often costly to obtain, skilled modelers, powerful computing devices, and they require solution of a complex system of non-linear, partial differential equations. As a result, provision of the necessary information base through the development and use of sophisticated physically based models is often prohibitively costly in terms of data collection and acquisition of modeling capabilities.

In the Sevier River Basin, real-time operations of the Piute Reservoir must face downstream uncertainties in the form of variations in losses and gains on the river mainstem. These result in travel times from the reservoir to downstream canal diversion points that are uncertain and vary as a function of the quantity of flow in the river and antecedent flow conditions. In addition, downstream canal operators and farmers change their water management decisions on a day-to-day basis to reflect knowledge of current economic and hydrologic conditions. These human behavioral factors place additional uncertainty on the shoulders of the reservoir operator. To contend with these uncertainties, the Piute Reservoir operator would benefit from a tool that would help decide on a near real-time basis how much water to release to meet water orders to canal operators located downstream of the reservoir. In other words, a common requirement for managing the reservoir that is operated on an "on-demand" basis is the anticipation of the quantity of water that must be released while accounting for losses or gains along the river and changing travel times to each downstream canal diversion point. Operation of the Piute Reservoir constitutes a case study were fine resolution decisions have to be made to meet downstream demands that will change in uncertain ways over the period between the time an action is taken to release water from the reservoir and the time when the downstream diversion takes place. A highly instrumented and controlled river basin, such as the Sevier, could be operated on an hourly (or more frequent) basis if sufficient detail is available in the information describing the present and desired future system state. For the operator of the Piute Reservoir, therefore, the desired output of the model is simply the hourly quantity of water that should be released from the reservoir. The information that must be made available to the model should include the data that describes current, and perhaps recent historical, flow conditions, various climate indices in the basin, and desired downstream canal diversions.

Identification of Inputs

The degree to which a dataset is judged to be of use to better predict optimal system operations decisions could be measured by many different functions, such as mutual information. In this study the relevancy evaluations were subjective as they depend on a perception of the relatedness of the given dataset.

Streamflow is the result of interactions between many hydrologic events, such as precipitation, snowmelt, evapotranspiration, infiltration, and groundwater recharge, and anthropogenic influences, such as reservoir releases and irrigation diversions. In this paper the short-term predictions of required reservoir releases are supported by hourly streamflow data that are available from 2000 to 2003.

Irrigation demands represent the quantities of water that farmers request be delivered to their head gates. Such requests are made one day in advance of when the deliveries are to take place, and are expressed to the reservoir operator by the various canal operators in the form of hourly measurements of canal diversions. Hourly data on these irrigation diversions for all the canals in the study area of the Sevier River are available for the years 2000 through 2003.

Weather information can directly influence the behavior of farmers and canal operators in the basin. The inclusion of temperature, relative humidity, wind speed, solar radiation, and total precipitation data as predictors can enhance the model performance. Historical daily and hourly weather data are available at many weather stations in the Sevier River Basin.

Management Approach

Establishing a reliable dynamic model for providing the necessary information to support advanced water resources decision making has always been an important concern for researchers and field operators. A real-time management approach within the context of data fusion is employed here. Figure 1 provides an abstract description of the set of functions and processes that may comprise a useful paradigm of machine learning and data modeling implementation for real time management of river basin facilities (modified from Mackay, 1992). Having a suitable database, one aims to estimate or predict entity states that provide insightful information to decision makers. This level of induction, which is the very first bold box in Figure 1, could be obtained by non-Bayesian methods, e.g., artificial neural networks (ANNs) and support vector machines (SVMs), or with Bayesian solutions such as relevance vector machines (RVMs).

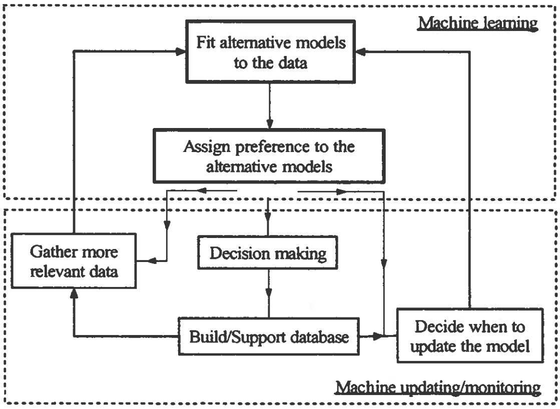

Figure 1: Abstraction of the data modeling process

Owing to its remarkable features and superior performance over non-Bayesian algorithms, RVMs have been adopted to the purpose of the models discussed here. Since there are a considerable number of design choices for RVMs, the second step of machine learning is to assign preferences for the set of plausible models, the second bold box of Figure 1. In this manuscript and for the objective of a fully automated machine, adaptive simulated annealing (ASA) is used to perform this level of inference (Ignber et al., 2004). This is known as models comparison, yet Bayesian methods are also used in this level by employing a quantitative Occam's Razor to penalize the selection of complex models and infer the most plausible model given the data; in other words, Bayesian methods have been implemented to determine the most plausible model in the sense that one maximizes the marginal likelihood of the data $\mathcal{D}$ given the set of hypotheses $\mathcal{H}$ (i.e. different model structure) $p(\mathcal{D}|\mathcal{H})$.

Having built the most plausible model, the second level of the framework is to use the machine as a decision support system. Hence its performance must be monitored and the model should be updated when needed. There are two events that might occur that indicate the model should be updated. One is the presence of a new data set that has not been previously exploited; the other is the case where there is concept drift, i.e., new trends in the data that the machine has not learned. For this purpose, SVMs have been used to detect an abnormality or novelty and thereby trigger the machine to adapt to these events by retraining.

Figure 2 illustrates the process flow from the raw data to the decision-making level, and where the concepts of model building (RVM), model selection (ASA), and novelty detection (SVM) fit in a fully automated data-driven paradigm.

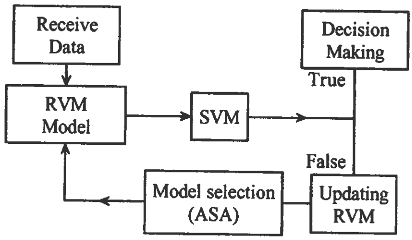

Figure 2: Model structure and process flow to achieve high-level inference.

RESULTS AND DISCUSSION

Reservoir releases must be made to address the conflicting goals of satisfying downstream demands with high certainty, while at the same time conserving water in the reservoir for use later in the season. This problem evolves from the hydraulic and hydrological complexity of the system. The proposed fully automated machine has been implemented for real-world data describing the Sevier River Piute Reservoir water delivery system. The collection of hourly data in the Sevier River basin is ongoing since 2001. Data from the 2001 and 2002 irrigation seasons were used to build the machine, while data from the 2003 irrigation season were used to check the validity of the machine when functioning in real-world conditions. The irrigation season in the basin generally extends from April to the end of October. There are eight inputs for the machine in the form of diversion orders at the different downstream canals, three inputs of streamflow from measurements made along the river downstream of the reservoir, one input representing inflow from Clear Creek (a major gaged tributary that is approximately one day travel time downstream of the reservoir), and one input in the form of a climate index. Clear Creek is an example of an uncontrolled tributary stream that discharges into the river in such a way that its spring and early summer diurnal fluctuations make downstream water management more difficult. The climate index is the first principal component of temperature, relative humidity, solar radiation, wind speed and precipitation.

Model selection involves the selection of values for the parameters so that the model output matches the measured behavior of the system as closely as possible. Kernels present nuisance parameters that are generally determined heuristically.

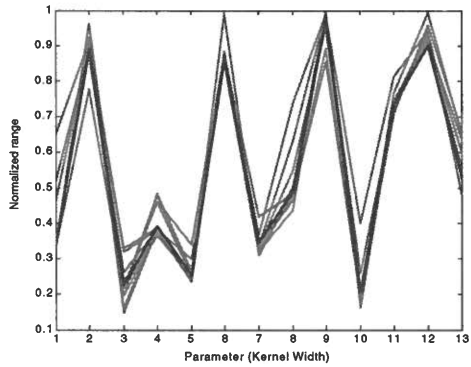

Figure 3: Normalized parameter space, curves corresponded to a set of Pareto solutions (gray), the selected set (solid line).

Arguably, ASA resulted in a sub-optimal kernel parameter data set, as is shown by the model performance illustrated in Figure 3. Douglas et al. (2000) argued that for the purpose of using the model for on-line forecasting, it is desirable to select a single representative parameter set that provides an acceptable trade-off in fitting of the different parts. Thus the bold line in Figure 3 represents the selected kernel parameter set.

Figure 4 shows RVM results for the irrigation season of 2003. Figure 4 also illustrates the 95% confidence interval of the predicted values. The machine removes the redundant features to improve the generalization abilities and it only utilizes 32 relevance vectors (RVs) from the full data set that was used for training (2001 and 2002 irrigation seasons). The RVM ignores the irrelevant inputs to reduce complexity and spurious overfitting. Therefore, it can be used to summarize the information by maintaining the major features of the data set via RVs. Some statistics of interest have been evaluated (Table 1) to test the machine performance (for more details about goodness-of-fit measures, see David and Gregory, 1999). Here, the predicted reservoir releases significantly deviated from the observed releases for the 2003 irrigation season over some time periods, and the confidence interval on the prediction was often very wide. In order to maximize the marginal likelihood of the data, ASA chose a narrow kernel parameter for some input dimensions, thereby suppressing their influence on the forecast release quantity.

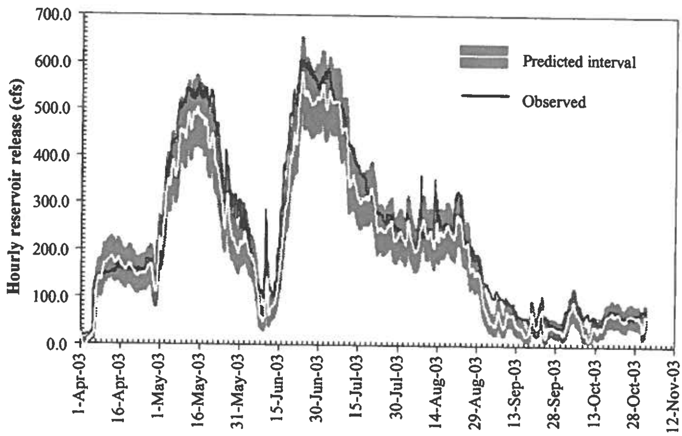

Figure 4: Time series plot of the actual versus predicted releases with confidence intervals.

Again, a SVM has been reformulated to provide a new algorithm, which is in line with Vapnik's principle, for detecting outliers and novelty (Scholkopf, 2000). Figure 5 shows a plot of the output $\rho = \sum_j \alpha_j k(\mathbf{x}, \mathbf{x}_j)$ on the test data set of the Piute Reservoir releases. We used a Gaussian kernel, which has the advantage that the data are always separable from the origin in feature space (Burges, 1998; Cristianini and Shawe-Taylor, 2000; Vapnik, 1995).

Table 1: Machine performance using different statistics. Robust performance measures have been evaluated of the smallest 85% residuals; raw ones are for all the data.

Statistic	RVM	RVM+SVM	RVM	RVM+SVM
	Raw Performance		Robust Performance	
Correlation coefficient (r)	0.983	0.991	0.990	0.997
Coefficient of efficiency (E)	0.932	0.981	0.964	0.993
Bias	-29.762	-4.783	-19.834	-2.627
Root mean square error, cfs	44.080	23.436	29.904	14.951
Mean absolute error, cfs	33.270	17.219	23.961	12.211
Index of agreement (d)	0.982	0.995	0.991	0.998

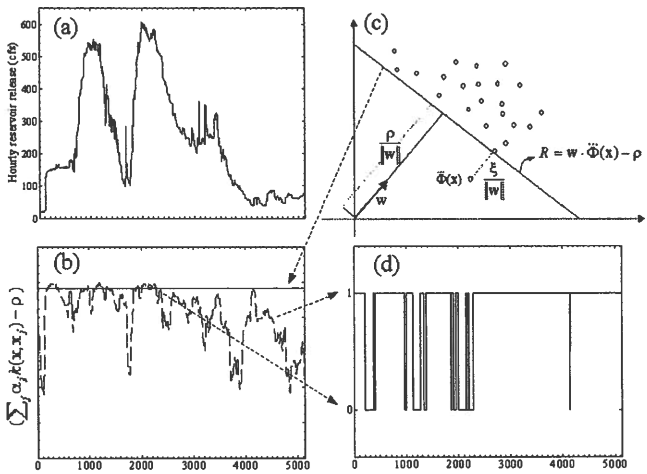

Figure 5: SVM results on the testing data. I (f (x)-ρ) takes the value +1 in a region capturing most of the data points and 0 at the input patterns that show either new trends or outliers.

As shown in Figure 5, the algorithm returns a value of zero to identify outliers and new trends in the data; this triggers the machine to retrain while exploiting all the new data that hasn't been used for training before. Figure 6 shows the results of the machine when linked to the SVM where it has been retrained to account for novelty. Due to this adaptation, the number of RVs increased to 36. The model performs remarkably well and Table 1 provides some statistics of interest for the full paradigm. These statistics further show that the new combination achieves a low error rate.

It is known that abundant data provide robustness (global robustness) for machine learning applications. To ensure good generalization of the inductive learning algorithm given scarce data, the machine has been built on many bootstrap samples from the original dataset to explore the implications of the assumptions made about the nature of the data. Figure 7 shows the results of training using different bootstrap samples.

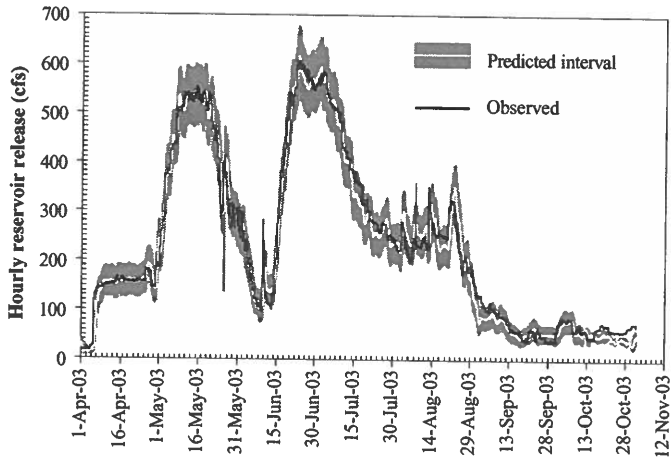

Figure 6: Time series plot of the actual versus predicted releases with confidence intervals for the RVM+SVM machine.

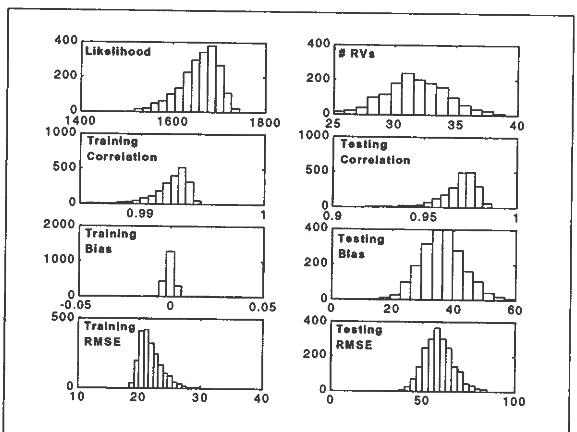

Figure 7: Statistics analysis of different bootstrapping samples.

To utilize the model in near real-time, the predicted reservoir releases can be provided to the reservoir operator, and then it is possible for the operator and and other experts to analyze, judge, and evaluate the results of the machine according to their own knowledge and experience. All in all, the performance results have demonstrated the successful implementations of Bayesian principles (RVM), model selection (ASA), and novelty detection (SVM).

SUMMARY AND CONCLUSIONS

In the Sevier River Basin the principal water problem is twofold: inadequacy and uncertainty of supplies. In this context, a reliable water supply planning policy, specifically during the irrigation season, necessitates acceptably accurate predictions of future water states. In this paper we have presented an operational approach to a decision aid for managing near real-time reservoir releases. While machine-learning techniques have great potential to be used in decision support systems, we believe they have not been fully exploited in water related issues. Growing evidence that there are streamflow variations during the season and from season to season, as well as shifts in climate indices (Kahya and Dracup, 1993; Lins, and Slack, 1999), has lead us to incorporate a novelty detection algorithm in the real-time decision support system. This paper explored the use of unsupervised support vector machines in a sequenced learning technique to recognize behaviors that are outside the norm, and then to trigger the RVM to learn to recognize new patterns.

One could view the present work as an attempt to provide a framework where different algorithms have been fused to better estimate future decisions and detect novelty trends. The approach presented uses a concrete paradigm with well-behaved computational complexity. Beven and Binley (1992) suggested that many models are over-parameterized and therefore result in equifinality. Equifinality is associated with the multiplicity of different possible combinations of values of model parameters. We argue, therefore, that the model structure proposed in this manuscript was formulated so as to avoid equifinality and ensure parameter uniqueness. Parametrically efficient RVMs (sparseness and parsimony), inclusion of many measures each emphasizing a different aspect of model behavior in model selection, and use of structural risk minimization via SVMs, collectively do not conclude equifinality.

Finally, one of the shortcomings of this approach is that, regardless of the parsimony of the model structure that reflects the most dominant characteristics of the system, it cannot be seen how a meaningful physical interpretation can be extracted from the resulting model definition. In spite of this, we believe that the imposed novelty detection tool ensures the persistence of the basic dominant characteristics and reflects any abnormality. One might be able to interpret such events in physically meaningful contexts. Another seemingly unavoidable disadvantage of the algorithm that handles novelty detection is that it detects an abnormality only after new data are available, that is after the learning algorithm performance starts to depreciate (Klinkenberg and Joachims, 2002; Olivier et al., 1999).

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SOIL MOISTURE DATA COLLECTION AND WATER SUPPLY FORECASTING

Randall P. Julander[1]
Tom Perkins[2]

ABSTRACT

Extreme deviations in hydroclimatic conditions are a source of considerable error in statistical water supply forecast models. Much attention has been given over the past years to the relationship between snowpack, precipitation and streamflow (Martinec, 1975, Hawley, et al. 1980, McCuen, 1993). These relationships tend to vary in strength, but in large part have been satisfactory for water supply forecasting purposes. Increased demands on water resources have led to crises in water management and ways are being sought to improve water supply forecasting. Many other hydroclimatic variables such as soil moisture are implicit in these statistical relationships. As long as these variables (soil moisture) remain proportional to the independent variables (snowpack, precipitation, etc.) in the forecasting relationship, then the model will be stable. If there is some amount of disproportion, then the model will most likely produce significant error. Such a case in northern Utah is presented with a limited database. The success of this instrumentation has led to a broader scale application with the goal of complete soil moisture and temperature sensor installations at all SNOTEL sites system wide. Currently, soil moisture data are being incorporated into water supply forecasting in an analog method with some success.

INTRODUCTION

The strong relationship between snow water equivalent and seasonal water supply has long since been demonstrated (SCS, 1970, Zuzel, 1975). These statistical relationships vary in strength depending on a host of factors such as latitude, elevation, and others. Forecast error in these statistical models is primarily in three parts: 1) statistical uncertainty in the forecast equation, 2) error associated with the measurement of the data, and 3) uncertainty associated with current or future hydroclimatic conditions. Statistical uncertainty is partly a reflection of the other two error sources. Data measurement error is assumed to be a constant as measuring techniques and sensors have been, for the most part, standardized (Amer et al. 1994). Reducing the error in the quantification of current or future hydroclimatic conditions has the greatest potential for reducing forecast error. It is unlikely that there will ever be sufficient data collection sites to completely quantify hydrologic parameters such as snowpack, precipitation and soil moisture, etc in time and space over every watershed of general interest and thus some

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portion of this error will likely remain as well. Also, unforeseen and radical seasonal fluctuations in hydrologic conditions, such as seen this year, can drastically affect projected water supplies from month to month in the forecast season. Soil moisture conditions across a watershed are generally presumed to influence seasonal water supplies from snowpack (Wetzel and Woodward, 1987). If extremely dry conditions are prevalent in the fall prior to the seasonal snowpack, then it is presumed that these soils have additional capacity to absorb and retain greater than normal amounts of snowmelt. This leaves a reduced amount to generate seasonal streamflow. Conversely, if the soils are saturated prior to the onset of snowmelt, it is presumed that, since the soils have less capacity for infiltration and certainly less storage, the majority of snowmelt should contribute directly to seasonal streamflow. After prolonged periods of dry weather, total potential snowmelt loss to soil moisture recharge can be significant. Assuming a 24 inch soil depth, 8 to 10 inches of snowmelt or more, could be lost to soil moisture recharge depending on soil type and condition. Some portion of this would eventually contribute to runoff and some portion would be lost from the immediate contributing system through either evapotranspiration or to deeper groundwater. In quasi-normal conditions, soil moisture is implicitly accounted for in statistical relationships whereas in extreme conditions, these relationships become unstable. These extreme conditions are often when accurate and reliable water supply information is most critical. In past attempts to quantify the impact of soil moisture on subsequent runoff, various types of surrogate indices have been used such as fall precipitation or base flow conditions with varying degrees of success.

The Natural Resources Conservation Service has installed soil moisture sensors at nearly 50 SNOTEL sites in Utah to determine if the use of such data can reduce the error associated with statistical water supply forecasting and be incorporated into various modeling applications. Some of these sensors, installed at the 2-inch, 8-inch, and 20-inch depths have been in place for 4 years, but most have only one to two years of data, thus only preliminary data are available for analysis. In Figure 1, the April 1 snow water equivalent at Trial Lake, is plotted against the Bear River at Stateline April-July streamflow. It is clear upon examination, that there are years of very high snowpack which result in very low streamflow and conversely, years that have comparatively low snowpack which result in high runoff. The status of soil moisture prior to runoff may be a dominant influence in these anomalies.

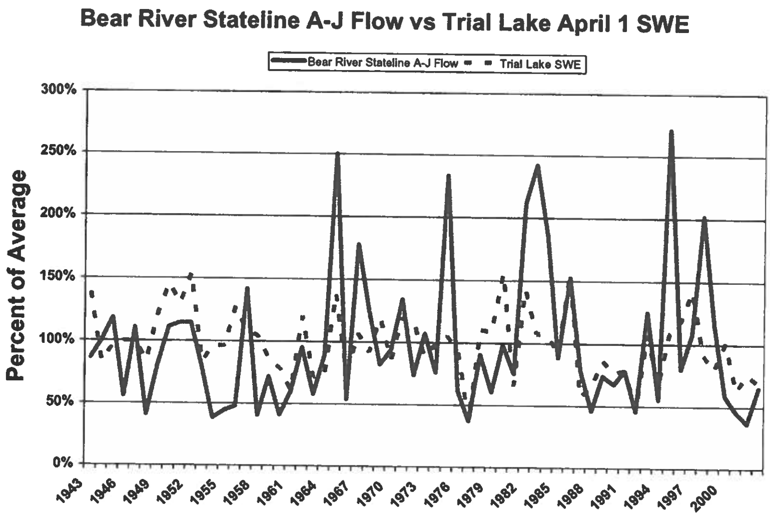

Figure 1. Bear River streamflow and Trial Lake snow water equivalent.

The soil moisture sensor installed is the Vitel Hydra Soil Probe. The operation principle is based on a high frequency complex dielectric constant and measures soil moisture by volume. Both the capacitive and conductive components are measured. A thermistor is used to determine temperature. It is designed for a field life of approximately 15 years and is constructed of stainless steel. It has an accuracy of plus/minus 3 percent in the absence of specific soil calibration and about 0.5 percent if soil analysis is done (Vitel, 1994). With the advent of a sensor with this longevity and anticipated stability, many of the complex problems associated with long term soil moisture monitoring may be avoided. This, in turn, could lead to a relatively accurate soil moisture index with the potential to reduce water supply forecast error.

Soil moisture is highly variable in time and space (Washburne, 1998). It is dependent on the type and depth of soil, slope, aspect, the type and amount of vegetation as well as climatological conditions such as temperature, precipitation and snowmelt (Diestal, 1993). Given this variability, point soil moisture data will need to be processed as an index, in much the same way as snowpack data currently is related to streamflow. The form of this index is currently uncertain because there is insufficient data to be able to make any reasonable quantification. It may simply take the form of average point data in a statistical relationship, i.e. the average value of the three soil moisture sensors at a particular time such as October 1, or March 1 of the forecast year. It could be a more complex formulation weighting various depths or times. There is certainly the potential for calculating a point soil moisture deficit and a potential net loss of snow water content to the soil given the appropriate soil physical data such as bulk density, transmisivity, etc. Even without the appropriate soils data, an index can be referenced to a static point (such as assuming the soil can hold a total of 10.8 inches of water in the upper 24 inches of soil profile) and used in a relational or linear context. In a point fashion, it will be important to eventually know the exact water holding capacity and calculate potential snowpack losses. This soil moisture deficit index might then be extrapolated to larger geographic areas or used in simple statistical water supply forecasting relationships. Given the analogy of soil moisture as a large reservoir (Hanks and Ashcroft 1980), a variation of soil moisture data or index could be a direct input to many of the Hydrologic Tank Models currently in use such as the Sacramento Soil Moisture Model.

Study Area

The watershed of primary analysis is Parrish Creek, in the Wasatch Mountains of Utah. General observations from other sites will be included that will demonstrate the potential for forecast improvement as well as sites that appear to have less value due to physical soil characteristics. The Wasatch Front, where Parrish and Centerville Creeks are located, is marked by a normal fault of large displacement. The west portion has been displaced downward several thousand feet, whereas the eastern Cottonwood uplift was displaced upward. It has many complex structural features such as several major synclines and anticlines as well as major and minor faults. The area is very steep, with the mountain crest in the study area near 9,000 feet and the various gauging stations mostly near 5000 feet MSL. The predominant sedimentary rock formations are sandstones, shales, conglomerates and limestones. Major igneous rocks are granite and quartzite. Major metamorphic rocks are migmatite, pegmatite, granulite, gneiss and hornblende-biotite granite. There is evidence of extensive glacial action in many of the canyons as well as glacial cirques. (Bell, 1952) Soils in the upper regions are generally coarse textured, immature, rocky and shallow; parent material was disintegrated in place by frost action. Many profiles are stony throughout (Olson, 1949).

Parrish Creek has a drainage area of 2.08 square miles above the gage elevation of 4,600-feet. There is historic evidence and records of flood and mud/debris flows in the past. Parrish Creek The watershed vegetation consists mainly of Aspen / Conifer stands at higher elevations with Sage Brush, Gambel Oak and various brushy species at lower elevations. The watershed orientation is westerly (Julander, 1988). The SNOTEL site is located in the center of the watershed at an elevation of 7740 feet MSL. The site aspect is westerly and the vegetation at the site location is primarily Aspen, forbs and grasses.

Centerville Creek is directly adjacent to Parrish Creek and has a streamflow gauging station maintained by the USGS with a fairly long record. It is very analogous to the Parrish Creek watershed in terms of elevation, aspect, geology, vegetation, hypsometric curve and orientation. It is slightly larger at 3.15 square miles. Centerville Creek streamflow will be used to correlate snow and soil moisture.

Analysis

In a fortuitous set of circumstances, peak snow water equivalent at the Parrish Creek SNOTEL site was essentially equal for three of the four years of data analysis, which gives more or less a constant in a mass balance context with regard to snowmelt input. Soil moisture and streamflows were, over that same period, highly variable giving a very good correlation and highly promising results from this small watershed. Figure 2 shows streamflow for Centerville Creek, SWE and a weighted soil moisture index for the Parrish Creek Watershed. For the first three years of data collection, the peak SWE was essentially equal at 26.8, 25.5 and 26.6 inches for the water years of 2000, 2001 and 2002. The total streamflow for the period of April through July for those years was highly variable at 841, 1199 and 1105 acre-feet respectively. The seasonal average for the period of record is 1,452 acre-feet. The range in flow for the study time period is 353 acre-feet which is 24% of the long term average, a significant deviation from what is ostensibly equal snowpacks or water inputs to a watershed mass balance. The question now being, can this variability be directly correlated to some kind of soil moisture index or is it insignificant when coupled with other snowpack losses such as sublimation or evapotranspiration? Other questions would be what kind of soil moisture index might explain the most variability? What time frame is most important - fall or spring moisture? What kinds of factors may influence soil moisture over time? In looking at the weighted soil moisture index, there are some complex processes occurring. With extremely warm, dry summers and falls over these years, the depletion of soil moisture over this time frame is readily apparent. However, during the winter months, soil moisture appears to rebound to some extent except the 2004 water year. At first, it was thought that this could be due to some soil surface melt from the snowpack but this was discounted when the total amount of water necessary to bring soil moisture from an index of 13% to 27% was compared to precipitation events and snow water equivalent records from the site.

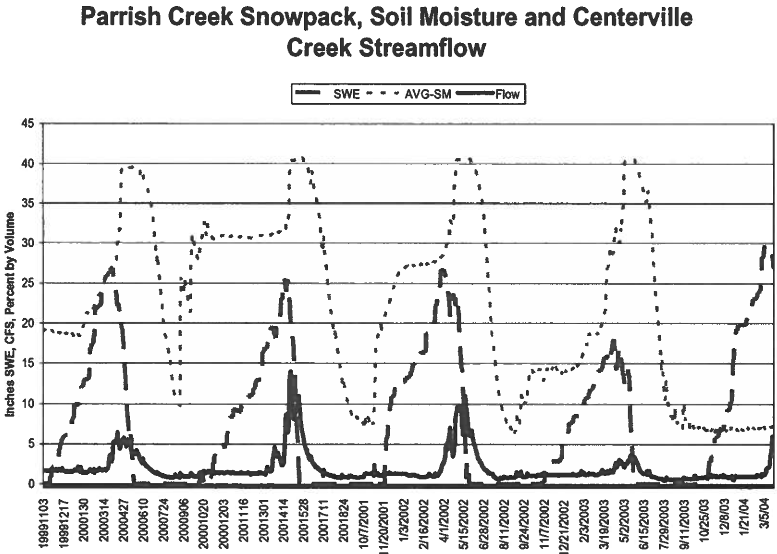

Figure 2. Snowpack, Streamflow and Soil Moisture.

The rebound in soil moisture may be due to the topographical convergence features of the site. It is in the very bottom of a small cirque on the watershed and potentially moisture from the surrounding slopes could migrate downward to the sensors over the winter period where it essentially remains till the beginning of ablation. Of particular note in Figure 2 is the fact that during the current 2004 water year, this phenomenon has not occurred and could be due to the longevity and intensity of drought in this area leaving very little moisture to migrate this year. With regard to the response in streamflow, the higher the soil moisture index in the three equal snowpack years, the higher the response in flow and conversely, low soil moisture severely limits flow. In the 2003 water year, note that soil moisture had less rebound in the winter months and thus going into the melt season, was able to take significant more snowmelt. This combined with 30% less snowpack yielded an extremely poor runoff season of only 494 acre-feet. If snowpack and streamflow had a strictly linear relationship, 30% less snowpack would have yielded runoff in the 750 to 800 acre-foot range, essentially double the observed flow. Given the fact that the March soil moisture index was near 15%, the lowest value of all years of data up to the current year, indicates that losses to soil moisture could easily account for the loss in flow and that the incorporation of soil moisture as a forecast variable could explain significant variability in current equations.

Using the soil moisture percent by volume data, one can calculate a relative estimate of the soil moisture deficit, or the potential amount of snowpack that, given the correct ablation circumstances, could be infiltrated to the soil and lost from direct surface flow to the stream. (Julander and Cleary, 2001) Using this deficit index, a simple multiple linear regression model was constructed using all five years of data available and compared to a regression model using snow water equivalent alone. The soil moisture deficit index used was a November as well as a March index to determine how far in advance soil moisture could reasonably portend an impact on runoff. Using snow water equivalent alone produced an R-square of only 0.40, extremely poor results considering that there were only 5 data points available for analysis. When the November soil moisture deficit was added to the April 1 snow water equivalent, the R-Square improved to 0.74. And finally, when using the March soil moisture deficit instead of the November, the R-square improved to 0.88, a significant improvement. The standard error was reduced from 718 down to 412 acre feet, also a significant improvement. This analysis appears to show that point soil moisture data has the potential to significantly improve snow melt based water supply forecasting at some locations.

In a broader geographic scale covering northern Utah, the past 5 years have shown tendencies at many sites towards less efficient runoff. That is to say, snowpacks seem to have had greater losses and have generated proportionately less streamflow during these mainly below normal snowpack years. Summers have been very hot and dry, depleting soil moisture which, in turn seems to be impacting runoff. Figure 3 shows just such a case for the Weber River Watershed. In 1999, a basin average snowpack of 82% produced streamflow of 100% to 120% of average on two watersheds within the basin. We do not know what the soil moisture condition across the basin was during that year, but the assumption is that it was sufficient for a very efficient runoff, since the seasonal runoff during the previous four years was above average. The very next year, 2000, snowpack was actually higher at about 90% of average but produced far less flow on the two basins, 30% to 60% of average. In the year 2001, with a far smaller snowpack, (62%) runoff is essentially the same, 30 to 55% of average. In the 2002 water-year, snowpack is again higher at nearly 82%, but runoff remains static at the 30% to 55% range. Finally in 2003, snowpacks are similar to the 2001 water year yet streamflow is markedly lower at just 15% to 20% of average.

If we correlate to just the Parrish Creek soil moisture site (the only site with sufficient data), the 2000 water year had a fairly dry March index of 18, fairly dry and the streamflow compared to the previous year was much lower. In the 2001 water year, the March Soil Moisture index rebounded to 31 and streamflow remained the same as the previous year but with nearly 20% less snowpack. In 2002, the soil moisture index decrease to 27%, not a great deal but again, streamflows are nearly the same as in 2001. However, the snowpack was nearly 20% higher, maintaining a solid relationship between flow, SWE and the March Soil Moisture index. During the 2003 water year, the snowpack was similar to

2001, but the watershed produced only 40% as much flow. The March Soil Moisture index during this time had fallen to its lowest point of 15, thus accounting for the difference in flow.

Weber River SWE, March Soil Moisture Index and Observed April-July Streamflow

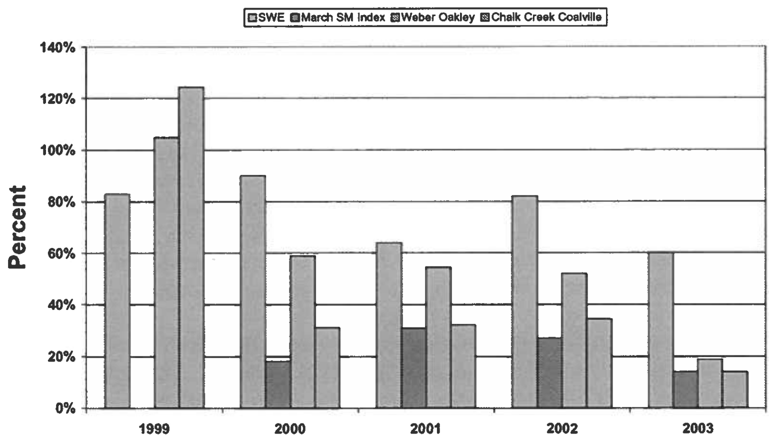

Figure 3. Weber Basin Average SWE, March Soil Moisture Index and Observed April-July Streamflow.

CONCLUSION

Preliminary results of soil moisture data seem to explain some of the wide error discrepancy between computer generated forecasts from SWE data and observed streamflow on Parrish Creek/Centerville Creek in northern Utah. The anecdotal use of soil moisture data as an indicator of abnormal conditions that could cause a significant deviation in the empirical relationship between SWE and observed streamflow is gaining acceptance and forecasts are being subjectively modified to include these conditions. In a more quantifiable context, previous year's data for streamflow, SWE and soil moisture can be used to proportionally modify current year's forecasts. The complex relationships between soil moisture, ground water contributions and runoff preclude more definitive analysis or a precise accounting of the total water balance of the basins. It is apparent that extreme deviations in soil moisture, such as those encountered in the past few years in northern Utah can have an extraordinary impact on streamflow, not explicitly accounted for in statistical forecast equations. Certainly long-term soil moisture data will give a much clearer picture of these complex interactions and hopefully, a reduction in forecast error.

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MULTI-BASIN MODELING FOR WATER SUPPLY OR, PLAYING 4-DIMENSIONAL CHESS AT YOUR DESK

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ABSTRACT

The City of Aurora, Colorado ("City"), obtains its raw water from three river basins, the South Platte, the Arkansas, and the Colorado. Because the City's rights are both geographically dispersed and varied in priority with other water users in these basins, the City's water resources staff must aggressively manage these resources and its facilities to ensure a reliable supply of water for its residents.

To allow the City's staff to analyze its existing system and quantify the benefits of potential projects, the City partnered with Hydrosphere Resource Consultants to build a model of its system. The model uses an optimization routine to allocate water in the basin, including the diversion of lower basin water at upstream locations through the use of river and contract exchanges. Because some of the City's rights in the Arkansas basin are junior to those of other entities, the City's model had to include all of the other major water sources and users in that basin. The City has worked extensively with other water users to ensure that the model accurately represents the senior operations. Accurately modeling other systems allows the City to anticipate how changes in operation by other water user's will affect the City's system yields and reliability.

This model allows the City to investigate alternatives for providing a reliable water supply using vehicles such as interruptable supply contracts and short term leases to reduce the variability of existing supplies. Such modeling allows the City to determine the amount of leased water it can likely put to use, the amount of storage required to hold its leased supplies, and the operations necessary to divert and store that water.

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BACKGROUND

Historical Development of Aurora's Raw Water Supplies

The City of Aurora, Colorado, is located in the South Platte River basin, approximately 5 miles southeast of Denver, just east of the foothills of the Rocky Mountains. When the City was platted in 1891, it consisted of four sections of land and 14 homes. The town initially obtained water from a well dug by a private water company. Additional wells were dug along the banks of Sand Creek were used to meet the city's growing demand.

As the town's demand outpaced its well capacity, Aurora turned to Denver to supply it with water. In the 1920's, Denver limited the number of new taps in the City. In the 1940's, Denver announced that it would not deliver water south of 6th Avenue or east of Peoria Street. As a result of these limitations, the City began pursuing its own water supplies.

In the 1960's, the City began buying irrigation water from ranches in the upper South Platte basin and transferring the consumptively used portion to municipal uses. In 1967, Aurora and Colorado Springs teamed to complete the Homestake Project, which diverts water from Homestake Creek and delivers it to Spinney Mountain Reservoir. In the 1980's the City transferred agricultural water rights from two ditches in the lower Arkansas River basin to municipal use. While these acquisitions added significant water to the City's water portfolio, they added significant complexity to the management of its supplies. Because the historical point of diversion is approximately 150 miles downstream of the City's intake, water is moved from the headgates to the intake via exchanges, which are highly influenced by the operations of others.

Presently, the City of Aurora has a population of approximately 290,000, and on average uses around 56,000 acre-feet of water per year. The City's water resources department works to ensure a reliable supply of water for its current and future residents.

Colorado Water Law

Water law in the United States is generally administered by the individual states. Typically water rights in the eastern U.S. tend to be based on the riparian doctrine, where landowners adjoining streams have the right to use the water in the stream. In the western U.S., states generally follow the prior appropriation doctrine, where those with the oldest rights may take water first. Colorado is a fairly strict prior appropriation state.

Part of the prior appropriation doctrine is that water not consumed during use must be returned to the stream for the benefit of downstream users. The exceptions to this principle include transbasin diversions and transfers of consumptive use portions of agricultural waters to municipal use. In the case of transbasin diversions, return flows can typically be used and reused to extinction. Where water is transferred from one use to another, the return flow portion of the original water right is left in the stream while the consumptive use portion may be used and reused to extinction.

WATER OPERATIONS

Water supplies

Located in the South Platte River basin, the City obtains water from three independent basins: the South Platte, the Arkansas and the Colorado. The City's South Platte supplies include both ground water and surface water rights. The surface rights are primarily senior agricultural rights that have been converted to municipal use, and junior direct flow and storage rights. The City's Arkansas basin rights are primarily senior agricultural rights that have been converted to municipal use.

Approximately three-fourths of the City's water rights are either converted agricultural rights or are transbasin in nature. This water may be used and reused to extinction, effectively doubling this portion of the City's water supply.

In average years, the City obtains approximately half of its supply from the South Platte, one fourth from the Arkansas, and one fourth from the Colorado. Because of the lower seniority of the City's South Platte water rights, the percentage from the South Platte decreases during dry years.

The City's Colorado River basin rights are transbasin diversions, taking water from the upper parts of the Colorado River through collection systems and tunnels. Because of the City's west slope storage, these rights are fairly reliable.

In the Arkansas basin, several of the City's rights are in the lower end of the basin, while its diversion for its delivery system is at the top of the basin. The City relies on both river and contract exchanges to move the water from its historical point of diversion to its intake. River exchanges allow a user to divert water upstream and replace it with water downstream, so long as intervening water users are not injured. A contract exchange allows two water users to trade water stored in one reservoir for an equal amount of water stored in another. River exchanges are adjudicated by the water court and receive a decree date, like other water rights. Contract exchanges may occur between any willing parties, and do not require state approval.

The Influence of Other Users

Because of the inter-dependencies of water rights within the hydrologic system, not even senior water rights can operate with complete disregard to other water users. This is particularly so for the City, which holds somewhat junior water rights. The City depends on physical flow in the Arkansas River to exchange water into the upper basin. The City is susceptible to reductions in yield if one of the large water users changes their operations, such as re-timing a reservoir release.

MODELING

Previous Modeling

In the past, Aurora's collection and delivery system modeling was limited to subsets of its system. Models were developed on an as-needed basis for individual collection systems, or for river basins, but not for the City's entire system. These models were of varying complexity, and ranged from spreadsheets to custom applications written in a programming language.

Because the City's system is connected by pipelines and tunnels that have finite capacities, modeling individual basins overlooked some of these system constraints. Modeling of individual basins also overlooked the relationship of supply and demand on a system-wide scale.

Model Plan and Development

In 2000, the City contracted with Hydrosphere to construct a model to simulate the City's operations in the Arkansas and Colorado basins, including the evaluation of current operations, and the impact to yields from various changes in operations and facilities. After a careful review of the City's modeling requirements, Hydrosphere identified three models that met the City's model criteria. Riverware, developed by the Center for Advanced Decision Support in Water and Environmental Systems (CADSWES) at the University of Colorado, Modified Simyield (MODSIM), a model developed by Dr. John Labadie at Colorado State University, and the ExcelCRAM developed by Hydrosphere, appeared to be suitable for the task.

Riverware is an accounting simulation model which uses an expert system framework for solving problems. It is difficult to construct a Riverware model that would simulate water rights priorities. In addition to water rights, the model also needed to be able to take into account preferences in facility use as well as the priorities of both traditional prior appropriation water rights and river exchanges. Hence, Riverware was eliminated from further consideration.

Both MODSIM and ExcelCRAM are simulation models that use optimization as a freamework to arrive at a solution. While both MODSIM and ExcelCRAM have similar capabilities, Hydrosphere recommended ExcelCRAM as the preferred model because of ExcelCRAM's ability to run multiple operations steps, which allows for modeling the complex exchange decrees and stipulations in the Arkansas basin. This in turn allows the user to track water from different sources as it moves through the system.

In 2004, Hydrosphere added the South Platte basin to the City's model. The third basin was necessary to place demand constraints on the yields from the Arkansas and Colorado basins. While the City's operations in the Arkansas basin are heavily influenced by the operational decisions of other users, the City's operations in the South Platte are much more predictable.

Cutting Edge Modeling Methodology

Modeling Aurora's raw water collection system requires the ability to allocate water by priority, simulate river and contract exchanges, and to manage and track water by origin and type. Hence, modeling the City's system can be likened to playing 4-dimensional chess, where the dimensions include the spatial extent of the stream system, the attributes of which change with the length and width of basin; the different types and ownerships of water, which are used by different entities in different locations in the basin for different purposes, and the return flows from which have different reusability characteristics; and the hydrology of the system, which influences both water supply and demand through time.

ExcelCRAM is based on the out-of-kilter algorithm, and is implemented in Microsoft Excel. Water systems are created in a graphical user interface using nodes and links to represent system features. In ExcelCRAM, all the operations are performed on the links, and nodes are used only as ways to join features. Unlike 4-dimensional chess, the model does not anticipate future actions, but optimizes the movement of water only for the current timestep.

ExcelCRAM has three features that facilitated modeling of Aurora's system. First, each link in the model can have a priority assigned to it, and the model solves the allocation by maximizing the total value of the water flowing through the network. Second, each link has a status assigned to it. The status can be open, closed, or fixed, where a fixed link is required to have the same flow as it did during the previous solution step. Third, the model uses operational steps (op-steps), which allows the user to run the same timestep repeatedly. In combination with the first two features, op-steps allow the user to model very complex situations.

Op-Steps

Like 4-dimensional chess, modeling complex water resources systems requires a well thought-out strategy, so that you can avoid getting into an untenable situation. ExcelCRAM's use of op-steps provides modelers with a strategic tool. Op-steps allow the user to run the model repeatedly for the same timestep. The status of links can be varied between op-steps either manually or by Visual Basic code. This ability to rerun the model while changing the status of the links allows the model to solve water allocation while tracking the ownership or type of water flowing through the system. The user can have ExcelCRAM run the model as many times as necessary to solve a specific problem.

Figure 1 shows how link settings would be used to complete a river exchange in three op-steps. In the first op-step the exchange links are closed, and water flows down the river to meet senior demands. In the second op-step, the links to the senior demands are frozen, so water cannot be diverted from them to a junior use. The exchange links are open, and any water not required to satisfy senior demands is routed from the river at the top of the exchange reach, through the exchange links which are parallel to the river, and back to the river at the bottom of the exchange reach. In the final op-step, water diverted at the top end of the exchange is routed into storage in the upstream reservoir, the middle of the exchange is closed, and water from the downstream reservoir is released to the bottom of the exchange to keep the river whole.

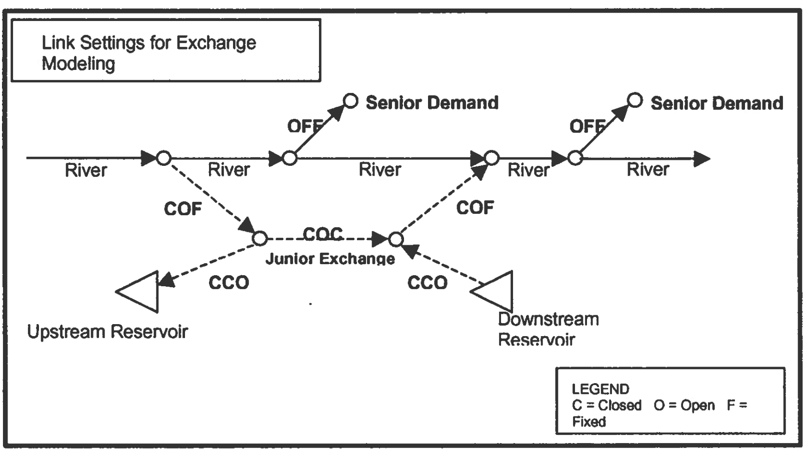

Figure 1. Schematic of a River Exchange

Model code is used to set the highs on the exchange links to the minimum of the amount of storage space available in the upper reservoir, the amount of water available for release in the lower reservoir, or maximum decreed rates of exchange.

On the Arkansas River, the order and amount of the exchanges into Pueblo Reservoir have been stipulated in water rights decrees. The difficulty of the exchanges from a modeling standpoint is that the exchanges are interdependent, where the first water user has the right to exchange 20 cfs, the second has the right to exchange 100 cfs, then the first has the right to exchange another 50 cfs, and then a third has the right to exchange whatever portion of 70 cfs the first user didn't use. This mosaic continues down to Aurora, which holds less senior exchange rights.

To accurately simulate the operation of the exchanges, the Aurora model runs each timestep eight times. The first distributes water native to the Arkansas basin. The second allocates water imported to the basin. The third through seventh are required to allocate exchange potential among the eight competing river exchanges, and the eighth is used to perform contract exchanges.

Like a chess player who tracks the moves made in a game, Op-steps are also used to track the water by its physical origin, ownership, and type (single use vs. reusable). This allows the user to color the water in the system so it can be tracked as it moves through the system over time.

RESULTS

The modeling effort has proved valuable to the City in several areas. The City is using the tool in development of a strategic plan and analysis of potential projects.

While modeling of Aurora's collection and delivery system is ongoing, the modeling to date has demonstrated that the City's unconstrained system yield is significantly reduced due to system constraints. This reduction in yield demonstrates the importance considering systems as a whole, and not rely on models that just look at a subset of its water system.

The modeling study did identify some opportunities for improvement in the existing system, and quantified the incremental changes that would occur with the construction of new facilities. However, modeling did not find any single change that would significantly increase the City's yield. This shows that given the existing system, past experience has come close to maximizing yields, and system operations are fairly well optimized.

Modeling also showed that there are places where Aurora's yields are sensitive to the operations of others, and to particular pieces of Aurora's own infrastructure. While there may be little the City can do to control the actions of others, it can identify what actions are most influential to Aurora, and provides the City with information about its vulnerabilities. Modeling also can predict the impact to the

City's yields if one or more key facilities were to fail, and the importance of maintaining those facilities.

BIG-PICTURE LESSONS

While modeling may not always be so enlightening, the size and scope of this project lead to some bigger picture conclusions that are worth passing on. First,

municipalities in Colorado have assumed that having collection systems in multiple basins minimizes the risk to a crippling drought. Runoff in 2002 showed that regional droughts can happen, and that it is not wise to rely on a multi-basin system as a single strategy for drought protection.

Second, conservation works. In the past, water resources staff in Aurora and other municipalities have stated that conservation would be the key to surviving a drought worse than what occurred in the historical record, and this belief was shown to be valid during 2002. Customers responded to voluntary and mandatory restrictions, significantly reducing demand. Mandatory conservation did cause economic loss through die-off of some landscape vegetation, but in Aurora, no one was without water.

Third, as Aurora has looked for new water supplies for its growing population, it has met resistance from those who may be affected by the transfer of water. Reallocation of water from other uses to municipal use will not be painless, though there are measures municipalities can take to minimize the impact on others. Aurora has implemented periodic leases of agricultural water to refill its reservoirs after drought, agreed to limit its exchanges to maintain minimum streamflows, and worked to develop projects that benefit both the City and the local region where the water will come from. Modeling can predict how water development will change operations, which in turn can help managers minimize the impacts on other users, the environment, and the basin as a whole.

DEVELOPMENT AND IMPLEMENTATION OF A FARM WATER CONSERVATION PROGRAM WITHIN THE COACHELLA VALLEY WATER DISTRICT, CALIFORNIA

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ABSTRACT

An farm water conservation program was created in May 2003 by the Coachella Valley Water District (CVWD) to reduce demand for Colorado River water following a reduction in annual supply of 109,000 acre-feet (135 MCM, 31%). JMLord, Inc. was hired to provide services to water-users within the District.

Key components of the 2003 program were water user training and field services. The program supported water user decision-making and led to reductions in farm water demand within the first 7 months.

The training program was developed to share the theory and practice of irrigation and salinity management. Weekly meetings were held from June to October, covering a wide range of topics. Activities included lectures, discussions, field demonstrations, and hands-on workshops. Water user participation was excellent.

Field services provided one-on-one interaction to implement the concepts of the training meetings. Services included irrigation scheduling, irrigation performance evaluations, salinity management, and feasibility studies for system improvements. Water users representing approximately 40% of the farmed area became involved in the program, and many identified reductions in water use.

Successful long-term conservation programs must focus on both achieving water savings and on verifying that the savings occur. The key to supporting water users in conserving water is developing trust by protecting trade secrets and by demonstrating the effectiveness of scientific management techniques.

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INTRODUCTION

The purpose of this paper is to provide a discussion of the extensive farm water conservation program developed and implemented by the Coachella Valley Water District, California (CVWD) during the last 7 months of 2003. A description of CVWD is provided, as well as a description of the factors leading to the creation of the program. Key components of the program are highlighted, and observations of the effectiveness of the program in promoting and realizing conservation are included.

BACKGROUND

The agricultural service area of CVWD is located at the north end of the Salton Sea, in Eastern Riverside County, California. The District is surrounded by the San Jacinto and Santa Rosa Mountains on the west and by the San Bernadino and Little San Bernadino Mountains on the north and east. The agricultural water service area, Improvement District No. 1 (ID1), encompasses 136,000 acres (55,000 ha), 103,000 acres (41,700 ha) of which are irrigable. Approximately 72,000 acres (29,100 ha) are irrigated annually[5]. Farmers in CVWD produce a diverse variety of crops including table grapes (17.7%), citrus (11.4%), dates (9.4%), lettuce (6.5%), bell peppers (4.7%), sweet corn (4.4%), and carrots (4.1%).

Irrigation water supplies from the Colorado River are supplemented by irrigation wells owned and operated by the water users. Annual canal water deliveries for irrigation are approximately 280,000 acre-feet (346 MCM), and annual groundwater pumpage for irrigation is approximately 90,000 acre-feet (111 MCM)[6].

Irrigation technologies and agricultural water management practices have changed significantly in CVWD since Colorado River water was first imported in 1949. As of 2002, Coachella Valley farmers have converted over 63% of irrigated lands to drip or sprinkler systems[7].

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[5] Levy, Tom (2000 – 2001) and Robbins, Steve (2002), 2000 – 2002 Annual Reviews, Coachella Valley Water District. P.O. Box 1058, Coachella, California 92236.

[6] Water Advisory Committee (WAC). March 2004. Water Management within Improvement District No. 1 of the Coachella Valley Water District. P.O. Box 1058, Coachella, California 92236. Unreleased Draft.

[7] Water Advisory Committee (WAC). March 2004. Water Management within Improvement District No. 1 of the Coachella Valley Water District. P.O. Box 1058, Coachella, California 92236. Unreleased Draft.

For many years, California has used more than it's legal entitlement of 4.4 million acre-feet (4.4 BCM) of Colorado River Water annually. Several agencies receiving the water including CVWD, Imperial Irrigation District (IID), and the Metropolitan Water District of Southern California (MWD) have been working for years to reach an agreement to reduce the State's demand on the Colorado. An important milestone of the negotiation process was December 31, 2002. Failure to reach an agreement by that time resulted in an instantaneous cut by the Bureau of Reclamation (BOR) of 800,000 acre-feet (990 MCM) to immediately curb California's annual use to the legal entitlement. If the milestone were met and an agreement forged by the end of 2002, deliveries would have been decreased gradually over 15 years, softening the reduction in water supply.

When December 31 came and passed and an agreement had not been signed, BOR enforced it's earlier warning and immediately reduced California's Colorado River supply. In order to allocate the reduced supplies among California contractors, BOR cut IID's 2003 water order of 3.1 million acre-feet (3.8 MCM) by 205,000 acre-feet (253 MCM). This cut was stopped by an injunction upheld by the U.S. District Court in April 2003, pending an analysis of IID's beneficial use of water by BOR under the Federal Part 417 process. The impact of this ruling on CVWD was a 109,000 acre-foot (135 MCM) reduction in water supply for 2003. The cut represented approximately 31% of the annual water order or 50% of the remaining supply for the year.

In response, CVWD adopted several measures in May to minimize adverse impacts on water users. The following measures were adopted:

- Temporary $15 per acre-foot surcharge for Colorado River water to increase the agricultural irrigation rate to $30.50 per acre foot.
- Requirement of non-agricultural users to convert to groundwater sources.
- Suspension of the water availability assessment until January 1, 2004.
- Encouragement of farmers to switch from canal water to private well water, where possible.
- Retention of JMLord, Inc. to provide training, fields services, computer software, and other farm water conservation support.

As an added measure, the District sought additional supplies from Palo Verde Irrigation District (PVID), another California contractor on the river. A temporary fallowing program was developed and implemented to transfer up to 80,000 acre-feet (99 MCM) from PVID to CVWD at a cost of $12 million.

Almost a decade of heated debate and intense negotiations resulted in the realization of the Quantification Settlement Agreement (QSA), signed by Secretary of the Interior Gale Norton October 16, 2003. This agreement will result in the largest transfer of water in United States history. The need for water conservation has not abated as a result of this agreement, however. In fact, the need continues to increase as supplies dwindle and demand increases. The events of 2003 served as a catalyst for the development of a farm water conservation program in CVWD, but the importance and value of the program has not diminished with the signing of the QSA and restoration of Colorado River water supplies. The program has been renewed for 2004 and is expected to continue at some level into the future. Water conservation is a critical component of CVWD's role as a public service agency.

TRAINING PROGRAM

A primary component of CVWD's 2003 conservation program was water user training. The objective of the training program was to provide explanation and demonstration of scientific and technical methods of farm water management to water users to allow continued independent operation following participation in the program. The following specific goals were identified at the outset:

- Provide a thorough understanding of the need to schedule irrigation frequencies and amounts to satisfy crop water needs.
- Provide a thorough understanding of techniques, both manual and computer, used to schedule irrigations based upon the relative capital and manpower available to the participant.
- Discuss and demonstrate the advantages of irrigation scheduling to enhance yield and crop quality.
- Discuss and demonstrate the impacts of irrigation scheduling on timing of harvest and the implications regarding better control and regulation of the time crops are put on the market.
- Discuss and demonstrate the optimization of fertilizer application by minimizing losses and the optimization of soil salinity levels through adequate leaching.
- Discuss and demonstrate the necessary scheduling adjustments that must occur for cultural reasons such as: seedbed preparation, germination, transplanting, and climate modification.

A sequence of educational meetings was scheduled and curriculum developed to meet the specific goals of the training program. The specific courses held are listed in Table 1 on the following page.

A total of twenty courses were held as part of the 2003 training program. Attendance for the meetings was excellent. On average, 3 CVWD personnel, 4 JMLord personnel, and 13 water users attended each meeting. The courses provided an excellent opportunity for water users to interact with the District and to communicate regarding District operations, water supply status, and factors influencing farm water use. Through the training meetings, water users representing approximately 25,000 acres (10,000 ha, 35%) of the farmed acreage in the District opted to become involved in field services offered under the program. Water conservation achievement awards were presented to 18 water users attending 5 or more meetings.

The 2003 program has provided insights into opportunities and constraints to improve farm water management practices in CVWD. Moreover, the implementation of an education program by the District has yielded insights into opportunities to provide a valuable, effective water management program that benefits all water users, both agricultural and urban. The following observations have been made regarding the training program:

- Many participants expressed interest in attending future courses.
- More courses should be taught in Spanish, or a translator should be present.
- Classes should focus on hands-on activities with a minimum of time in the classroom.
- A course catalog should be provided well in advance to allow the participants to plan to attend courses that relate to their operations directly.

Table 1. Schedule of Courses

Date	**Meeting Topic**
June 18, 2003	Introduction to CVWD Water Conservation Program
June 25, 2003	Irrigation Scheduling Concepts
July 2, 2003	Irrigation Scheduling Strategies
July 9, 2003	Soil Moisture Measurement
July 16, 2003	Crop Water Use I
July 23, 2003	Crop Water Use II
July 30, 2003	Translating Crop Water Use into an Irrigation Schedule
August 6, 2003	Manual Methods of Scheduling I
August 13, 2003	Manual Methods of Scheduling II
August 20, 2003	Computer Methods of Scheduling I
August 27, 2003	Computer Methods of Scheduling II
September 3, 2003	Soil Moisture Measurement by the Feel Method (Field Activity)
September 10, 2003	Soil Moisture Measurement Using Tensiometers (Field Activity)
September 17, 2003	Salinity Monitoring and Reclamation (Field Activity)
September 24, 2003	Distribution Uniformity Evaluation (Field Activity)
September 25, 2003	Distribution Uniformity Evaluation (Spanish, Field Activity)
October 1, 2003	Irrigation System Maintenance (Field Activity)
October 2, 2003	Irrigation System Maintenance (Spanish, Field Activity)
October 8, 2003	Irrigation Timers and Controllers
October 15, 2003	Other Methods of Determining Moisture and Stress

FIELD SERVICES

Another key component of the conservation program was water management field services. One-on-one interaction between the water user and the consultant served to reinforce topics covered in the training program. Numerous specific services were provided, allowing the participants to evaluate and utilize those applicable to their specific operation. Demonstration of the effectiveness of scientific management techniques and promotion of independent adoption by the water user were emphasized. The following services were offered:

- Soil Moisture Monitoring
- Crop Evapotranspiration Calculations
- Irrigation Recommendations
- Irrigation Performance Evaluations
- Salinity and Drainage Monitoring
- Leaching Recommendations
- Feasibility Studies for System Improvements

Irrigation scheduling (soil moisture monitoring, crop evapotranspiration calculations, and irrigation recommendations), irrigation performance evaluations, and salinity management activities (salinity monitoring and leaching recommendations) were the most popular services among program participants. Irrigation scheduling was implemented on approximately 3980 acres (1610 ha) including row crops, dates, table grapes, and citrus. Irrigation performance evaluations were performed on approximately 780 acres (320 ha) including microirrigation systems and sprinklers. Salinity management was implemented on approximately 4120 acres (1670 ha) including composite sampling, grid sampling, EM38 "Salt Sniffer" surveys, and bed/row scale sampling throughout the wetted pattern of the irrigation system. A feasibility study was conducted for a 270-acre (109 ha) ranch producing row crops with furrow irrigation.

The following observations were made regarding the irrigation scheduling services under the program:

- Most participants were interested in implementing irrigation scheduling if assistance was provided.
- Some participants were concerned about the confidentiality of their practices.
- Some participants felt that it is not feasible to implement frequent soil moisture monitoring independent of the program.
- The high level of irrigation technology present in CVWD increases the potential to optimize water use.

The following observations were made regarding the irrigation performance evaluation services under the program:

- Most microirrigation systems in the Coachella Valley were designed well to minimize pressure differences and maximize distribution uniformity.
- Distribution uniformity for most systems is dependant on maintenance including regular flushing, filter setup and maintenance, and chemical injection to prevent bacteria and algae.
- In many cases, nonuniformity occurs due to low system pressures, where small differences in hose pressures lead to significant differences in flow.
- In many cases, there are opportunities to run fewer blocks simultaneously to maintain system pressures.

The following observations were made regarding salinity management services under the program:

- Soils in the Coachella Valley are highly variable. Soils may vary significantly in texture, compaction, and related hydraulic properties both across the field and through the profile.
- Lack of adequate drainage can seriously hinder the ability to leach salts effectively.
- There are opportunities to target high salinity areas in many fields, removing the maximum quantity of salt per unit of water applied.

The following observations were made regarding feasibility studies under the program:

- Areas receiving water from the end of CVWD laterals may experience fluctuations in delivery flows that reduce the ability to irrigate uniformly and efficiently.
- Fluctuations in delivery flows can result in inordinately high water and labor costs.
- Improvements to District and/or farm irrigation systems may be feasible and could greatly improve flexibility in water management by water users.

WATER SAVINGS

The catalyst of this program was a critical need to reduce canal water demand to survive a water supply shortage. The success of the program was demonstrated by the ability of the agricultural economy to reduce water demands and survive the shortage. Accordingly, the focus of the program was to implement conservation practices and achieve real water savings as quickly as possible.

The feasibility of continuing the program depends upon the ability to quantify the amount of water conserved through each of the field services provided and through the education program. The effort to quantify water savings may require an equal or greater amount of energy than the effort to actually achieve savings. Verification of water savings resulting from specific practices provides the necessary accounting to establish conservation incentives and drive water savings using market forces. These incentives may come from District cost savings, farm cost savings, and urban cost savings.

On average, growers participating in the field services reported water savings of 0.7 acre-feet per acre (21 cm). Applied to the 9140 acres (3700 ha) for which field services were provided, total savings are estimated to be 6400 acre-feet (7.9 MCM). If growers applied the same management practices to their entire acreage, total savings could be as great as 17,500 acre-feet (21.6 MCM). These values provide a rough estimate of savings, and future efforts must provide more detailed verification of actual water savings resulting from specific conservation practices.

Recorded Colorado river diversions for 2003 were 28,600 acre-feet (35.4 MCM) below the average annual diversions from 1990 – 1999. Three causes for decreased diversions have been identified. The three causes are:

- Farm Water Conservation
- Increased Groundwater Pumping
- $15 Per Acre-Foot Increase

The causes of decreased diversions are interrelated. For example, an increase in agricultural water rates may have served as an incentive to implement conservation practices otherwise not feasible. Likewise, the increased rate likely caused some water users to pump groundwater in lieu of canal water.

CONCLUSIONS

Educational programs coupled with one-on-one field services provide a valuable mechanism to foster communication and interaction between the District and it's agricultural water users. The key to supporting water users in conserving water is developing trust by protecting trade secrets and by demonstrating the effectiveness and feasibility of scientific management techniques.

Real opportunities to save water at the farm level exist. Incentives may be required to implement conservation practices where the cost savings to the water user alone are not sufficient. Cost savings to the District, urban water users, and other agricultural water users may provide the market forces needed to implement conservation practices.

Successful long-term conservation programs must focus on both achieving water savings and on verifying that the savings occur. Verification of water savings is a necessary condition to establish mechanisms that use market forces to drive agricultural water conservation. Verification of water savings may require an equal or greater amount of energy than the effort to achieve actual savings.

GILA RIVER INDIAN COMMUNITY — MANAGING A MULTI-SOURCE CONJUNCTIVE USE WATER SUPPLY FOR LONG-TERM SUSTAINABILITY

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ABSTRACT

The Gila River Indian Community Water Rights Settlement Act of 2003, when enacted, will restore to the Gila River Indian Community a water supply necessary to sustain them on their tribal homeland. The settlement provides water from nine water sources, including delivery from four irrigation districts, treated municipal effluent, irrigation return flow and supplemental ground water. Rehabilitation of their irrigation system will expand irrigated acreage and the importation of additional surface water will change the ground water balance for the Reservation. The groundwater resource must be managed to protect and use the existing non-saline ground water, provide for fresh water recharge and production zones in the future and maintain capacity for containment of saline percolation from irrigation. To effectively manage this complex water supply and maintain protection of the aquifer, a water resource decision support system (P-MIP DSS) is being developed. The P-MIP DSS will integrate the various water sources, water demands, and associated economics using a combined surface-ground water model that addresses both water quality and quantity. The DSS will be used for strategic planning and annual operational guidance. The ground water and surface water monitoring components of the DSS have been completed and the model development is initiated, with completion slated for 2006.

INTRODUCTION

History

Quoting the Community Website: "*The Gila River Indian Community (Community) is an alliance of two tribes, the Akimel O'odham (Pima) and the Pee Posh (Maricopa). The Community was established by Executive Order in 1859 and formally established by Constitution in 1939. The largest reservation in the*

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Phoenix metropolitan area, the Gila River Indian Community covers nearly 600 square miles and borders such cities as Phoenix, Tempe, Mesa, Gilbert, Coolidge, and Casa Grande. In the last few years, with concentrated economic development that leads to a continuing increase of agriculture, industrial, and recreational activities, the "People of the River" significantly have moved the community from federal reliance toward greater self-sufficiency.

"The Akimel O'odham traced their roots to the HuHuKam. These early people farmed the Gila River Valley from 300 B.C to 1450 A.D. and developed extensive irrigation systems by digging hundreds of miles of canals to supply water to their fields. Following this practice, the Akimel O'odham irrigated thousands of acres of land to plant and harvest.

"Sometime in the mid to late 18th century, the Akimel O'odham welcomed into the Gila River valley a migrating tribe that called itself Pee Posh, "The People." Moving into the open desert lands east of the river, the Pee Posh eventually became allies of the Akimel O'odham and like their allies, became farmers in the Gila Basin." (GRIC, 2003)

Pima and Maricopa Indians were irrigating an extensive area of land with water diverted from the Gila River when early Spanish explorers (circa 1700) visited what is now central Arizona. After the United States acquired the Arizona Territory (1848 and 1853), non-Indians settling upstream diverted most of the river's usable flow (Franzoy Corey, 1985).

To improve the water supply for downstream users, Coolidge Dam was built on the Gila River upstream of the reservation between 1924 and 1928. While this reservoir was to supply both Indian and non-Indian farmers, the water supply turned out to be inadequate for the acreage that had been developed and water shortages continued. Beginning in the late 1930's, irrigation wells were drilled to help with the water shortage, but shortages persisted and the irrigation system promised was never fully completed or adequately maintained, resulting in the loss of irrigated land (Franzoy Corey, 1985).

Water Rights Settlement

On March 25, 2003, Senator Jon Kyl (R-AZ) introduced the Arizona Water Settlements Act (S. 437), also referred to as the Central Arizona Project Settlement Act of 2003. Title II of that Act authorizes the Gila River Indian Community Water Rights Settlement. The settlement agreement is the result of 13 years of negotiation between 35 parties, including the Gila River Indian Community (Community), the Federal Government, and various water users in the Gila River basin. Under the agreement, the Gila River Indian Community will receive a permanent entitlement to 653,500 acre-feet of water per year. This water supply is intended to meet the municipal, residential, industrial, recreational and commercial water requirements of the Community and supply irrigation water to approximately 146,000 acres of crop land. As a part of the settlement, funding is provided to enhance the water delivery system, to connect the various sources, and deliver water to all 146,000 acres of agricultural lands.

Water Supply

There are nine sources of water identified in the settlement agreement. While the water right from these nine sources totals 653,500 acre-feet per year, some sources are highly variable, with ground water used as the balancing supply. The sources also vary in water quality and cost and some have associated storage while others are direct flow. They also enter the reservation at a number of locations as shown on Figure 1. Table 1 summarizes the sources of water identified in the settlement agreement and the general parameters associated with each source. This high variability in water sources leads to challenging water management, especially when coupled with the requirement to deliver water to municipal, residential, industrial, environmental, recreational and agricultural uses while managing water and salt levels in the aquifer. A quick review of Figure 1 points out the complexity of the water balance problem.

Table 1. P-MIP Water Source Descriptions

Water Source	Description	TDS – mg/l
San Carlos Indian Irrigation Project	**Existing water supply with both direct flow and storage water. Highly variable supply.**	**Mean - 785**
Central Arizona Project	Decreasing supply with time as upper basin develops.	Mean - 550
Salt River Project	Deliverable at up to 6 locations. Has some storage, but at lower priority.	Mean - 734
Chandler Exchange*	Delivered as produced with no storage. Some blending required.	Mean – 1,200
Mesa Exchange*	Same as Chandler Exchange except different delivery location.	Mean – 1,200
Haggard Decree	Limited to west side only. Delivered as return flow from SRP w/supp. ground water	Drain – 1,060 Well – 2,480
R.W.C.D **	Delivered through the RWCD Canal.	Mean - 734
Drains	Non-regulated return flow entering the reservation. Expected TDS about 775 mg/l	Mean - 775
Ground Water Wells	Existing and new wells on reservation. Used supplemental to surface supply. Widely varying annual diversion. TDS will change with time from irrigation losses and recharge from flows in the Gila and Santa Cruz Rivers.	Current range 550 – 3,600

* Reclaimed water from Chandler and Mesa is received at no cost in exchange for their use of Community CAP water. Delivery is 1.25 times the CAP water.
** Roosevelt Water Conservancy District

[6] Reclaimed water from Chandler and Mesa is received at no cost in exchange for their use of Community CAP water. Delivery is 1.25 times the CAP water provided to them.

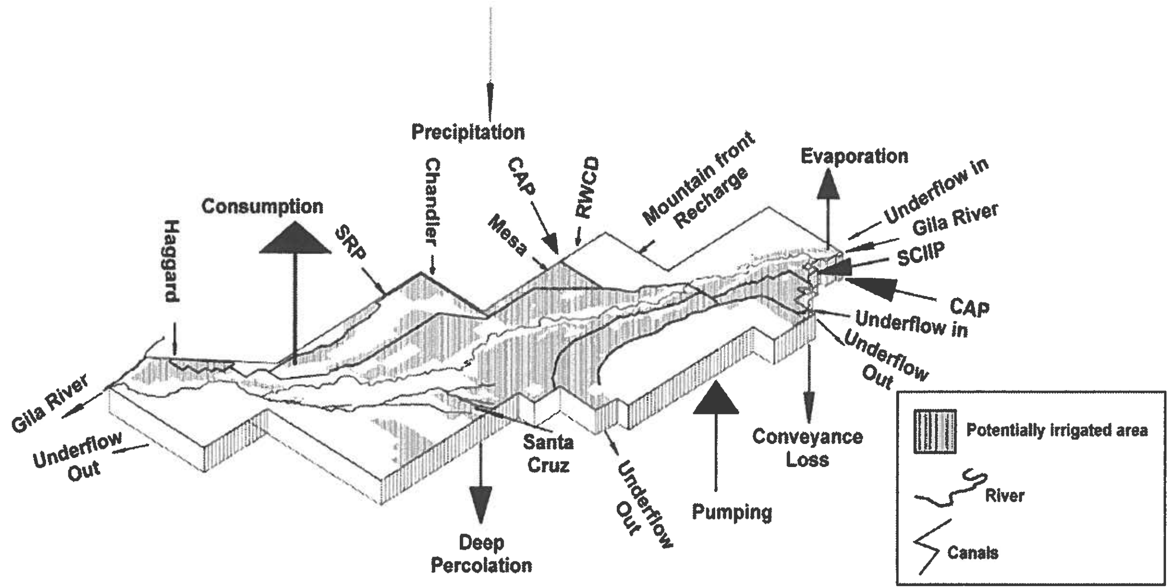

Figure 1. Water Balance Schematic for the Gila River Indian Reservation Showing Water Sources

COMPREHENSIVE WATER MANAGEMENT PLAN

In 1985 a master plan for water development was completed for the Community, providing preliminary goals for development of land and water resources (Franzoy Corey, 1985). The plan considered agricultural, residential, municipal, commercial, industrial and environmental uses. The central focus of the master plan was the development of a water conveyance and delivery system to supply these various uses.

In 1997 a programmatic environmental impact statement (PEIS) was prepared dealing with the completion of the Pima-Maricopa Irrigation Project (P-MIP), the title given to the water conveyance system envisioned in the 1985 master plan (GRIC and EcoPlan, 1997). The PEIS committed the Community to "develop a comprehensive water management document that will provide the framework to guide the Community in realizing the highest and best use of its land and water resources"(GRIC and EcoPlan, 1997). In August 2001 a Draft Comprehensive Water Management Plan (Plan) was developed (Keller-Bliesner Engineering, et al, 2001) with the following goals:

1. Protect the quantity and quality of Community land and water resources, guaranteeing sustainability of use through future generations.
2. Put water resources to their highest and best use, consistent with Community objectives.
3. Provide a stable and equitable system of water allocation and pricing that optimizes the use of water resources, consistent with Community objectives.

The Plan recognizes the complexity involved in meeting these goals with a diverse and variable water supply and a range of competing uses with different tolerances for water shortage and different economic returns. It identified the need for strategic planning to provide economical development of the water supply while protecting the sustainability of the ground water aquifer.

As the water supply system is developed, the irrigated acreage is planned to increase from the present 20,000 acres to over 146,000 acres. Increasing the irrigated acreage will increase the stress on the aquifer, but will also increase the irrigation return flow. Under normal irrigation practice, the salt concentration of the deep percolation water would be about four times that of the irrigation water. As the deep percolation reaches the aquifer, the upper zones will see an increase in salt concentration. Maintaining sustainability will required careful management of pumping and recharge zones.

The primary recharge zones for the aquifer are along the river channels, where relatively higher quality water can be maintained. The Plan envisions initial concentration of pumping from wells in the agricultural lands, removing the economically recoverable good quality ground water prior to it becoming unusable due to mixing with the return flow. The increased pumping will develop cones of depression in these areas, allowing storage space for the low quality deep percolation, while the water levels build in the fresh water recharge zones. As the water quality deteriorates and pumping levels increase beyond economic levels in the initial well fields, new wells will be developed along the natural recharge zones, with artificial recharge zones developed between the agricultural zones and the well fields. Such a development scenario will postpone the need for artificial drainage, maximize the recovery of high quality ground water and allow for sustainability of the ground water resource.

In addition to this important strategic planning, operational planning is needed each year to determine priority of water delivery from the eight surface water sources and to identify supplemental pumping requirements from the well field. Operational planning will optimize the use of the water to avoid wasting unregulated supplies, and prioritize delivery of the other sources to meet Community goals and manage water costs. Such operational planning will require identification of potential water shortages and provide water allocation information to farmers with sufficient lead time to determine cropping changes that might be needed.

The Plan highlighted the need for a decision support model that could support strategic planning by analyzing the quantity and quality of the available water supply over time (multiple years) in conjunction with a range of demand and supply assumptions. The model also needed the capability to provide operational planning support annually. To meet both these uses, the model must have the capability to analyze both the surface water and ground water supply and the interaction between them in terms of quantity and quality and include an economic component to provide guidance in long-term and short-term decision making.

Such a model requires continuous updating of data, so a resource monitoring program was established to collect the necessary hydrologic data to operate the model. The monitoring plan includes both the ground water and surface water data necessary to forecast the water balance shown in Figure 1, including total salt balance.

An electronic database has been developed containing historical surface water data. It has the capability to link directly to web-based sources, accept input from flow monitoring sites that have been established at three surface water inflow locations, and accept manual input of data sources not available electronically. It is designed to capture all major surface water inflow to and outflow from the Reservation.

A second database has been developed to store all available information on the ground water resource, including detailed well information. A monitoring program has also been established to collect quarterly water level and water quality data from a network of wells and continuous water level data from select wells located throughout the Reservation. These data will be used to calibrate, update and refine the ground water model.

P-MIP WATER RESOURCES DECISION SUPPORT SYSTEM

The Pima-Maricopa Irrigation Project Water Resources Decision Support System (P-MIP DSS) is presently under development with plans to have it operational by 2006. The model is designed to simulate delivery of water resources to the various uses within the framework of the goals and objectives of the Plan and economic constraints. It will consider priority of use and priority of delivery by source for any planning horizon on a monthly time-step. The economics portion of the model will allow computation of potential agricultural returns, determine pumping and water costs and allocate any subsidies deemed appropriate and necessary by the Community. Constraints on development limits, ground water pumping and management of return flow will also be determinable by the model.

The model will have two major components: The Overall Water Resource Analysis Component, OWRA and the Ground Water Analysis Component, GWA. The OWRA component will utilize the functionality of IRR-SIM, an irrigation development simulation model developed by Keller-Bliesner Engineering. The general structure of the model is shown in Figure 2.

The GWA is based on MODFLOW (MacDonald and Harbaugh, 1988) for hydraulic analysis and MT3D (Zheng, 1990) for water quality determination. The OWRA and GWA modules will be interfaced analytically to determine lag in the unsaturated zone. The OWRA will pass the spatially distributed pumping schedule, recharge (natural and artificial), return flow, and water quality by source to the GWA on a monthly time-step. The GWA will then compute spatially distributed head and water quality and pass the corresponding pumping lift and water quality time series back to the OWRA . Well locations are to be provided as an input to the model but will be refined through model analysis.

Since the result of the GWA operation influences the available water quality and pumping lift for irrigation, the two components will operate iteratively to solve the water quality interactions between surface and ground water as shown in Figure 3. The iterative loop should close to acceptable differences in a few iterations. After a number of analyses are completed, the initial conditions will be more precisely defined, resulting in less iteration.

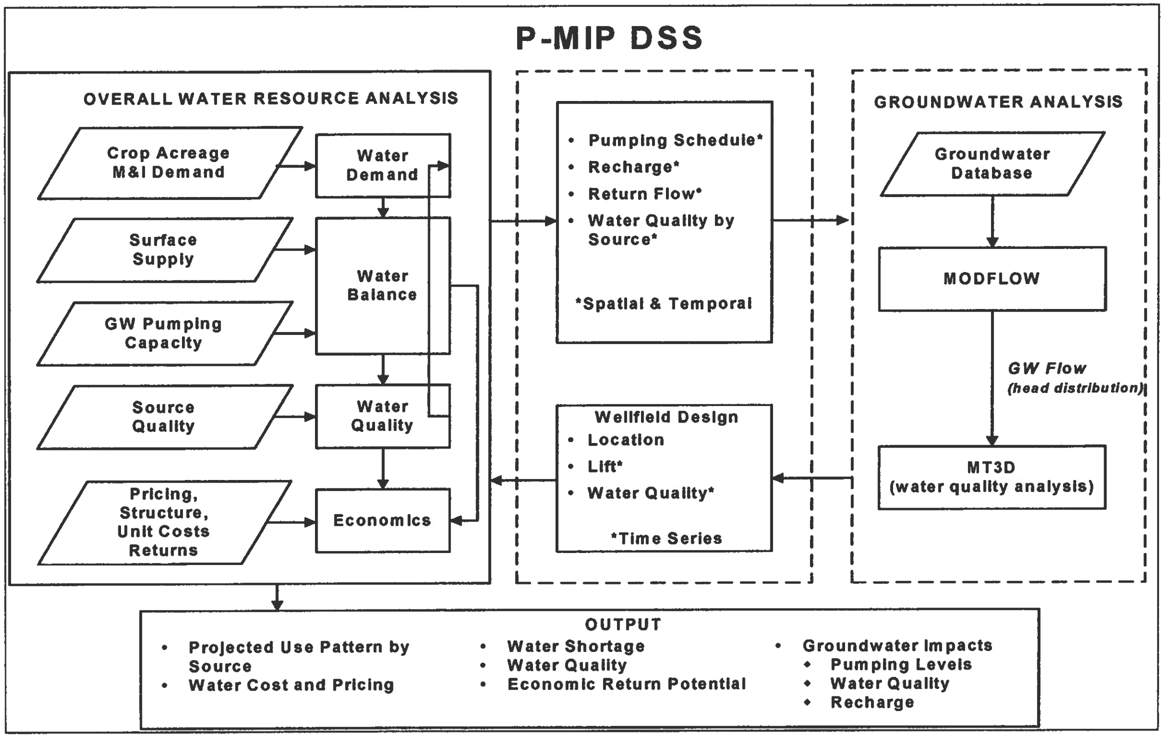

Figure 2. P-MIP DSS Model Structure

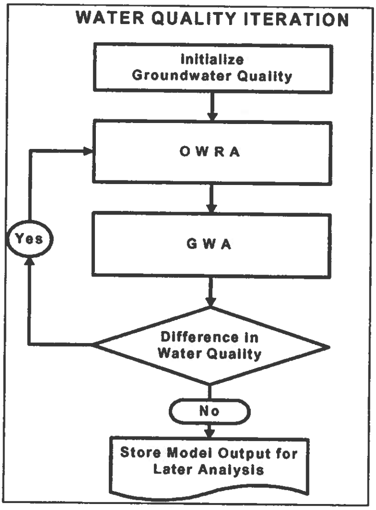

Figure 3. P-MIP DSS water quality iteration process

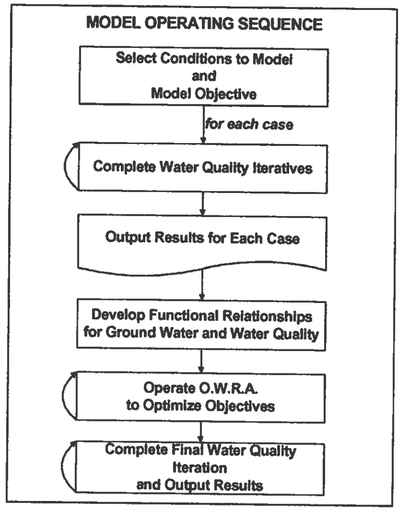

Figure 4. P-MIP DSS operational sequence

Model operational sequence is presented in Figure 4. Model operation begins with the definition of a given set of conditions and selection of a model objective. For example, the objective may be to determine optimum project size, assess water cost, determine return potential and ability to pay, or optimize well field design. With initial conditions and objectives set, a range of cases must be defined and the model operated to establish the conditions for each case. From the set of cases, functional relationships for pumping lift and water quality will be developed for the selected development parameter. With the functional relationships developed, the OWRA can be operated to optimize the desired condition. The objective in developing the functional relationships is to limit the number of GWA runs required, thus reducing the overall model execution time. A set of operational constraints, to include both water resource limitations and economic factors (e.g., excessive pumping lift), will be developed as a part of the overall water resources management tool to guide the decision process.

Crucial to the success and reliability of the iterative modeling process is data management. All input and output data from each iteration must be kept in electronic form for later analysis. A Microsoft Access database will be developed and used to store and query data. The database will provide ArcView GIS with information to provide graphical output of model simulation results.

The OWRA component is the main control module for P-MIP DSS. It computes demands by location, assesses surface water supply, assigns priorities, manages shortages, routes supply to demand and computes costs and returns. It also provides linkage to the GWA, passing spatially distributed pumping schedule and return flow for computation of demand, head and water quality with time.

The GWA component will evaluate the long-term effects of pumping and irrigation on the ground water quantity and quality. The MOD-FLOW based model will be configured to represent ground water conditions within the boundaries of the Reservation, with appropriate boundary conditions set to allow representation of pumping conditions in adjacent pumped and non-pumped off-reservation areas. On-reservation data collected in the baseline monitoring program together with available off-reservation data will be used to update and refine model calibration over time. The mass transport numerical component, MT3D, will simulate the transport of salts in the saturated zone. Water and salt movement in the unsaturated zone will be modeled analytically, with relationships built into the OWRA, allowing the appropriate lag on water and salt between the ground surface and the water table to be considered.

CONCLUSIONS

When finally authorized by Congress, the Gila River Indian Community Water Rights Settlement will restore to the Community a reliable water supply and provide funding to assist in its development. The Comprehensive Water Management Plan, when completed, will provide guidance for the development and protection of this critical resource, consistent with the goals of the Community. PMIP-DSS, utilizing state-of-the-art modeling components, is the key to finalization of the Plan and continued management of this critical resource.

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PERCEPTIONS CAN STOP WORTHWHILE GROUNDWATER BANKING PROJECTS

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ABSTRACT

In 1990, the author identified a 13,600-acre ranch in Madera County in the San Joaquin Valley, California, where up to 600,000 acre-feet of imported water could be stored in a "pumping hole." The site could be readily connected to the federal Central Valley Project (CVP) and the California State Water Project (SWP) by a two-way canal with low pumping lifts.

Between 1990 and today (2004), several parties have been interested in developing a groundwater banking project for regulating their water supplies. The initial studies were prepared for the Metropolitan Water District of Southern California and the Westlands Water District in the San Joaquin Valley. A more comprehensive study was prepared for a private party who acquired the ranch in 1991. Following feasibility studies, the ranch was sold to Azurix, a subsidiary of Enron, in 1999. It was subsequently sold to a water development corporation when Enron collapsed.

Over the years, participancy interest was expressed by several parties. Local support by neighbors ranged from positive initially to subsequent organized opposition. There was acceptance to having a local landowner operate and maintain a bank because of a belief that issues could be resolved in the courts, if necessary. There was strong opposition to an "intent agreement" between the private landowner and the U.S. Bureau of Reclamation (USBR) and the San Luis and Delta-Mendota Water Authority. The opposition was based on an expected inability to influence project operations by USBR. There was even greater opposition to Azurix. A number of claims were made by landowners and county supervisors including (1) importation of selenium from Mendota Pool, (2) taking and selling local groundwater, (3) crop damage to adjacent trees by high water levels, (4) groundwater levels would be lowered "excessively" during extraction, (5) urban areas would take over local groundwater, and others. During this period, extensive technical studies, including environmental studies further demonstrating project feasibility, were undertaken. When Enron collapsed, the effort was dropped—temporarily. The ranch was acquired by a water development company, which is working with local interests.

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It is important to have straightforward local involvement. Unsuccessful attempts were made to secure support from the state-federal Cal-Fed Program for water development. There was skepticism and statements that the project would never be undertaken. With this and other proposals, there appeared to be state staff opposition to any private water development. This case demonstrates that opposition based on partial or speculative information can stop development.

INTRODUCTION

Utilization of empty storage space in aquifers has long been a key component in conjunctive use of surface water and groundwater. In California, the practice was widely formalized over 50 years ago with artificial recharge of groundwater. These operations, principally in Southern California and the San Joaquin Valley, provided both seasonal and long-term carryover storage for dry periods. The latter role has been generally called groundwater banking.

The purposeful investigation of groundwater banking opportunities has been accelerated by the impacts of surface storage on the natural environment. Groundwater banking is generally more environmentally benign than development of instream resources with surface storage. However, groundwater banking has its own particular issues, many of which relate to pumping rights, water quality and management.

A SAN JOAQUIN VALLEY OPPORTUNITY

In 1990, Bookman-Edmonston (B-E) investigated banking opportunities for the Westlands Water District (Westlands), a large irrigation district, and the Metropolitan Water District of Southern California (MWD), an urban water supplier. These districts were interested in coordinating the use of their supplies for their mutual benefit. The focus of the studies was in the areas both north and south of the San Joaquin River generally west of the City of Fresno. Pumping for irrigation had lowered water levels in this area and created empty storage space.

This investigation identified an opportunity in western Madera County where water could be delivered to Mendota Pool on the San Joaquin River, to the banking area and recovered through a two-way, 12-mile canal utilizing the Delta-Mendota Canal of the federal CVP. The CVP supplies water to Westlands and other areas. The CVP and the SWP, from which MWD receives a major portion of its supply, are interconnected at San Luis Reservoir, a joint SWP/CVP facility. This connection affords opportunities to take water from a groundwater bank through exchanges with other CVP and SWP users. The 13,600-acre Madera Ranch is centered over the pumping hole. Only 2,745 acres of the former racehorse ranch were irrigated. The ranch site is shown on Figure 1, *Location of Madera Ranch, San Joaquin Valley, California.*

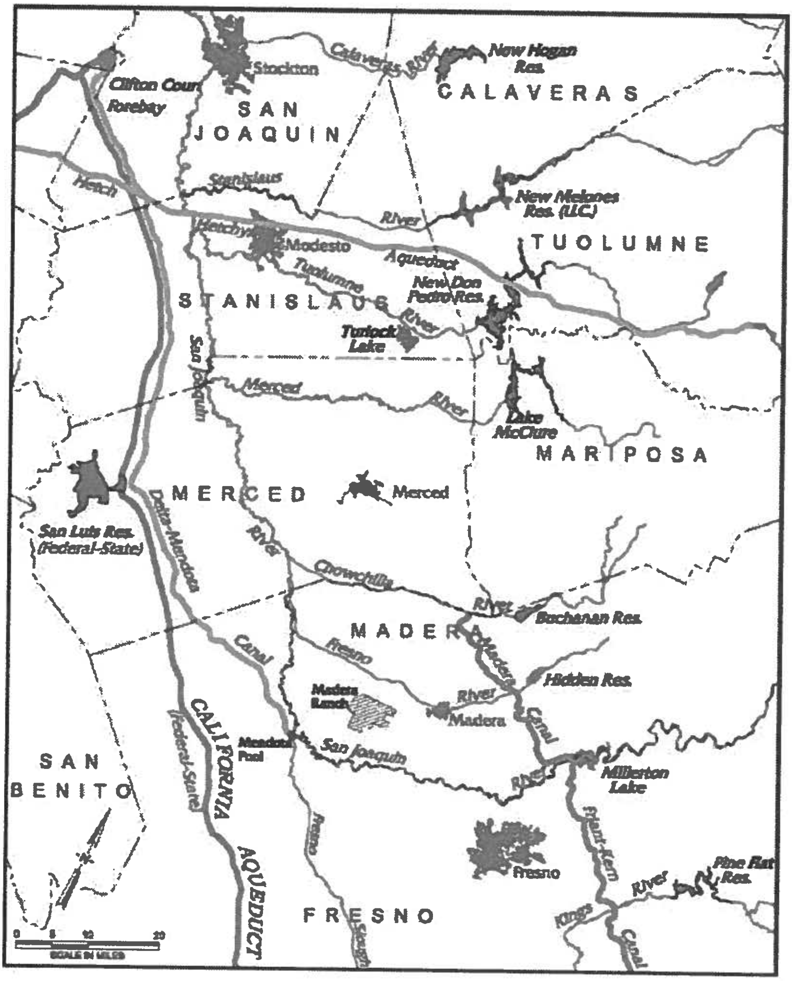

Figure 1. Location of Madera Ranch, San Joaquin Valley, California

The large pumping hole, with capacity for up to 600,000 acre-feet, also underlies surrounding farmland served only by groundwater. Long-term pumping without adequate recharge has created a pumping hole in the unconfined aquifer above the extensive confining Corcoran clay. This subsurface condition allows percolating water to directly recharge the depleted storage space.

MWD was exploring other supplemental water supply opportunities. Recognizing increasing local concerns regarding the political power of MWD and the concern about operations by Westlands outside of its district boundaries, the districts elected to not pursue this project.

A SECOND LOOK

In 1990, B-E was engaged by private parties who needed a firm water supply of about 15,000 acre-feet annually for a residential/destination resort in Oak Flat Valley, which is in western Stanislaus County on the edge of the Coast Range Mountains. Several alternative sources of water were available during winter months of most years, but storage would be needed for the summer months and dry years. The most cost-effective delivery system would be the California Aqueduct, but it does not have delivery capacity in some months.

The development partnership formed the Western Hills Water District. One of the partners had acquired Madera Ranch and Western Hills entered into an agreement with the owner to develop a storage project on the ranch.

Western Hills planned to buy unregulated water from an existing project in the Sacramento Valley. To secure regulation during dry years and delivery capacity in the California Aqueduct, Western Hills entered negotiations with MWD to regulate MWD's variable water supply at Madera Ranch, along with its own water, and to use some of MWD's capacity in the California Aqueduct for deliveries from Clifton Court Forebay in the Sacramento-San Joaquin Delta throughout the year.

MWD was also pursuing other options for regulation and elected to not pursue storage at Madera Ranch.

A THIRD LOOK

Recognizing the potential to develop a groundwater bank as a service to or in partnership with public agencies, the owner of Madera Ranch engaged B-E consulting services to pursue other options.

During the 1992 to 1999 period, preliminary design of facilities and discussions with several potential banking participants were undertaken. Over 90 trenches were excavated throughout the ranch and a quarter-acre percolation pond was operated for about 60 days to supplement soil surveys to estimate potential infiltration rates. Operation studies of conveyance, recharge, extraction, and direct or transfer recovery were made. Preliminary cost estimates for alternative sizes of projects were prepared. Technical memoranda were prepared for use in discussions with potential users. The owner's development concept was self-financing the construction and operation of all facilities on the ranch and a two-way canal with pumps to connect with the Mendota Pool and the CVP Delta-Mendota Canal. Bank users would pay for banking services through some form of put/take and storage fees. They would also be responsible for wheeling and capacity exchanges in the CVP and SWP facilities.

Additional storage was needed by the USBR for operation of the CVP. Discussions were held to attempt to develop arrangements with the USBR to pay for storage services in a privately owned groundwater bank, which would not be a part of the CVP. The USBR conducted its own operations and preliminary cost studies. Local concerns and reservations about USBR involvement in groundwater were beginning to be voiced.

The USBR concluded that it could not pay for private storage services. However, the USBR was interested in exploring an arrangement with the San Luis and Delta-Mendota Water Authority, composed of CVP contractors, under which the Authority would take the lead in arrangements with the owner of Madera Ranch. An "intent agreement" was drafted. This level of definition for project implementation created more and louder opposition to USBR involvement. Also, Westlands was a member of the Authority and a strong political entity. Local representatives believed that, if the landowners developed the bank, they could resolve any issues with the landowner in the courts, if necessary, but not with the USBR. Carefully drafted contracts would not be enough. The USBR and the Authority decided to not pursue the project any further.

Partnerships with other public entities were also not materializing. The one entity with the best operational match was skeptical of involvement with a private party. Several private businesses, however, were exploring water transfers and banking in California and approached the owner about a joint venture.

A FOURTH LOOK

After evaluating several proposals, the ranch owner entered into a sale-development agreement with Azurix, a subsidiary of Enron, which was involved in several water development projects. He believed that Azurix's experience in other water marketing programs would be helpful as well as providing additional financial backing.

As a tax-paying, farming neighbor, the owner was considered "one of them," who met from time to time with landowners in the local coffee shops. Involvement by an outsider like the behemoth Enron was not well received. Nevertheless, there was a strong effort to develop sound technical data and work with local interests.

More drilling was carried out. Two additional, fully instrumented percolation basins were operated for about 90 days. Preliminary alignment of a two-way canal to Mendota Pool was defined and a cost estimate was prepared. Recharge basins and extraction wells were preliminarily located. The quality of local and imported water sources was evaluated. Groundwater put and take modeling was conducted. Maximum and minimum groundwater levels during put and take cycles were estimated from modeling studies. Subsidence potential was assessed. An environmental impact report was prepared. Field trips for all interested parties were conducted.

While there was some quiet local support, a dedicated campaign of opposition developed. Some genuine concerns, which could be adequately addressed, were raised, but several emotional claims were made.

It was maintained that selenium, which is in drainage water on the west side of the San Joaquin Valley, would be in the limited amounts of groundwater that enters Mendota Pool. It was contended that this would pollute the groundwater basin and create problems similar to the waterfowl deformities at Kesterson Reservoir. It was argued by some that the basin would be depleted during extended take periods and by others that it would be so high during put periods that trees in adjacent orchards would be killed. The usual claim of takeover by urban interests was stressed. Large banners on the sides of several "cotton wagons" compared Azurix to MWD. The County of Madera passed an ordinance that required a permit to undertake groundwater banking. A congressman who represented the area was prompted to issue an opposition statement.

The financial and management interests of Azurix collapsed with the Enron collapse in April 2002.

A FIFTH LOOK

The limited residual interests of Azurix were acquired by a water development company and B-E was engaged to help develop a project. Some of the former Azurix employees continued to reorganize the pieces and to work with local interests to develop a more limited project. The Madera Irrigation District (MID), a CVP contractor served from Millerton Lake through the Madera Canal, has surplus water in some years and shortages in other years. Additionally, at times there is surplus water in the San Joaquin River at Millerton Lake over and above all downstream demands and rights. Some of the CVP supplies from Millerton Lake are also surplus in certain years. MID has storage and water rights on the Fresno River. These supply opportunities have been basic to the formulation of a smaller local banking project in which put supplies would be conveyed to the bank through the MID distribution system. The take water would be pumped back through canals modified for reverse flow for use in MID during water-short years.

Plans for this project have evolved slowly as acceptance of a local banking project has developed. To aid financing, consideration is being given to banking water for other CVP contractors served from Millerton Lake through the Friant-Kern Canal. Their dry-year take water would become some of MID's Millerton Lake supply while MID would pump and use the other district's groundwater from the bank. The local project would not have a two-way canal connection to Mendota Pool. Engineering and environmental studies and reports are largely completed.

LESSONS

Through the course of all of the studies, the principal issue was control and management. Uncertainties about relying on the private sector for public water supplies were also a factor. In some key settings, another issue was the unspoken, but apparent, opposition by certain key staff members of the Department of Water Resources (DWR) to water development by the private sector. During the time when DWR was working through the Cal-Fed organization and attempting to identify specific banking projects, the Madera Ranch project was omitted from the list and from consideration, even though the project was well-known and the omission was pointed out. Some staff members opined that the project would never be built.

In large measure, the acceptance of a project at the local, state or federal level depends on whether the entity "owns" the idea. Various real and perceived objections can and will likely be raised if the participation is reactive to ideas instead of proactive in developing ideas.

CONCEPTS OF GROUND WATER RECHARGE AND WELL AUGMENTATION IN NORTHEASTERN COLORADO

Stephen W. Smith[1]
Rachel J. Barta[2]
Donald O. Magnuson[3]

ABSTRACT

In northeastern Colorado, severe drought plus recent state court rulings have caused new and increased pressures on water rights. The current drought has been analyzed and is now thought to be a 300-year event based on proxy data obtained from tree rings. The drought factor, dramatic regional growth, transference of water from agriculture to municipal, and the increasing price of water have all put water rights under new and increased pressures.

Tributary wells in the South Platte River Basin, in particular, have been severely impacted because of recent State Supreme Court rulings. In response, several ditch and canal companies have implemented their own ground water recharge programs and well augmentation plans to replace out of priority depletions to the river caused by well pumping. The approaches that several canal companies have used in developing a long term strategy are described. Interestingly, the dynamics of ground water recharge and well augmentation programs also dovetail nicely with canal modernization strategies and SCADA.

In particular, the efforts of the New Cache la Poudre Irrigating Company and the Union Ditch Company are described to include application for new junior water rights, implementation of ground water recharge programs, and filings of augmentation plans for member wells in their respective service areas.

INTRODUCTION

Contentious issues have never been in short supply in the arena of Colorado water rights. That is particularly true today. In recent years, the authority of the State Engineer to approve substitute water supply plans has been successfully challenged and this put a 30-year-old augmentation plan for approximately 4,000 wells in the South Platte River basin in jeopardy. In fact, the Groundwater Appropriators of the South Platte (GASP) is gradually being dissolved. GASP was heavily reliant on leased water to meet timed well depletion obligations. As a result of GASP's demise, many subgroups of the 4,000 wells have formed, some

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as individual farm well groups, and some as larger groups, often under the auspices of the mutual irrigation companies.

Mutual irrigation companies logically get involved in well augmentation plans because they typically hold the decree on behalf of the shareholders under the ditch and because many of those shareholders are well owners, recently well owners needful of a suitable augmentation plan.

Although a rather small group of engineers and attorneys has been involved in well augmentation plans in the past, the current situation has provided both opportunity and necessity for additional technical expertise. Also related, Colorado State University has been actively involved and "in the fray" so to speak in providing useful supporting technical models[4]. These models, described further in a later section, allow the engineers to build timed depletion models on a transparent platform for conformity, better understanding of technical minutia, and most importantly, reduced time in both building (for the applicant) and scrutinizing (for the objectors) depletion models to be used in substitute water supply plans, augmentation plans, and ultimately in water court proceedings.

This paper describes some concepts of ground water recharge and well augmentation and comments on the process and the recent experience.

WATER RIGHTS IN COLORADO

Colorado was the first state to develop a system of water rights and laws based on the prior appropriation system. The core of the system is "first in time, first in right." So, if you were the first to divert the water from a stream, then you are the first priority on the river, and so forth. Calls on the river are satisfied according to the priority or priorities enjoyed by the water right holder. This approach, started in the mid-1800s, has worked quite well for Colorado and other western states.

In the late 1960's, a State of Colorado statute legally recognized that tributary ground water is hydrologically connected to surface water[5]. Consequently, both ground water and surface water are administered under Colorado's prior appropriation system. Colorado's water supply can come from either surface or tributary ground water sources, both of which are governed in the same way.

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[4] Another paper will be presented at this conference by Dr. Luis Garcia that will describe details of the technical models noted here.

[5] When this paper refers to ground water, it is referring to tributary ground water that is hydrologically connected to surface water in streams and rivers. This should not be confused with deep ground water, which is not regulated by the prior appropriation system in Colorado.

WELL AUGMENTATION

When the State of Colorado determined that tributary ground water and surface water should be administered together, they also determined it necessary to develop well augmentation plans. An augmentation plan is a water court approved plan designed to protect senior water rights, while allowing junior water rights to divert water out of priority (CFWE, 2003). These plans insure that the out-of-priority ground water depletions from junior wells are augmented (replaced) at the proper time, location, and quantity so as not to injure more senior water rights.

Since the late 1960's, over 4,000 well owners in the South Platte Basin have belonged to the GASP well augmenting entity. This entity provided replacement water for well depletions on a year by year basis by primarily leasing surface water. Over the last 30 years, GASP had operated under a temporary augmentation plan (otherwise referred to as substitute water supply plan), which was approved by the State Engineer annually. Compounded in part by drought and recent legislation in the State Supreme Court, these 4,000 wells are now required to file permanent augmentation plans by the end of 2005.

In general, the process behind a well augmentation plan is to: (1) determine ground water depletions caused by wells, (2) analyze replacement water sources needed to insure senior water rights are not injured by the depletions, and (3) administer and account for the operation of the plan.

Over the last year and a half both the Union Ditch Company (Union) and the New Cache la Poudre Irrigating Company (NCLPIC) have been in the process of refining their augmentation plans, which were filed with the water court in 2003. Figure 1 shows the Union Ditch service area, which is located southeast of Greeley. A major component of an augmentation plan is an engineering analysis used to determine the lagged effects of ground water pumping on the river. These depletions must be analyzed in the context of replacement water sources that are needed to insure injury does not occur. This paper will discuss some of the key components of this engineering analysis, with particular reference to the plans submitted by NCLPIC and Union.

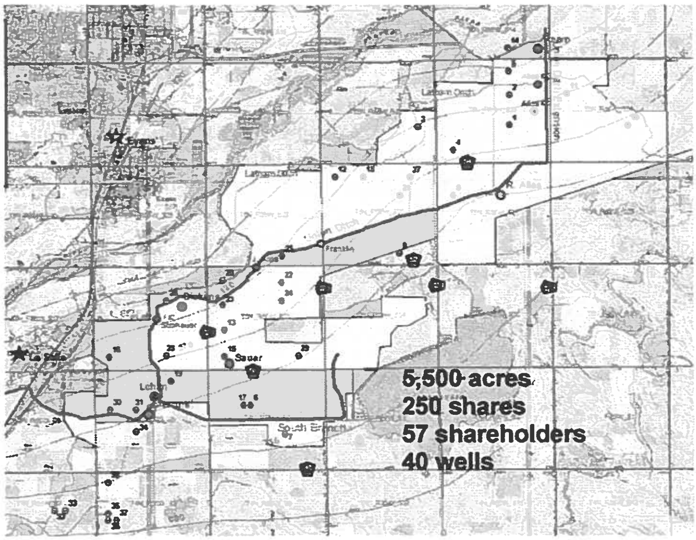

Figure 1. Union Ditch Company service area.

ENGINEERING TOOLS AND MODELS

The most widely used engineering tools and models used to support augmentation plans in the South Platte Basin have been developed by the Integrated Decision Support (IDS) group at Colorado State University (www.ids.colostate.edu).

The Consumptive Use Model (IDSCU) is used to determine a detailed water budget for farms. Using farm characteristics, surface water supply, and weather data, the model can be used to determine the total water requirement for a farm, the water available from surface water to meet farm water requirements, and the amount of ground water needed to satisfy farm water requirements not met with surface water supplies.

The Stream Depletion Factor Model (SDF View) and the Alluvial Water Accounting System (IDS AWAS) include several methods that can be used to determine the movement of ground water from the river to the well. Conversely, these models can also be used to determine the movement of ground water from recharge ponds to the river.

Simply stated, when a well is pumped there is a depletive effect on the surface water but the impact may not be immediate. Likely the effects of pumping are felt days, weeks, or even years later.

As an example, if the well were very close to the river, even adjacent to the river, the effect would be almost identical to a direct diversion on the river. Colorado law recognizes this in that a well within 100 feet of the river is administered exactly like a headgate. Conversely, if a well is far from the river, the effects of pumping do not reach the river for many days. See Figure 2.

The time delay in Figure 2 is expressed in days and termed the stream depletion factor or SDF. Stream depletion factors are used to determine the lag time from when water is pumped from the aquifer and when the depletion happens in the river -- the larger the SDF, the more delayed the impact on the river (directly proportional to the squared distance from the river).

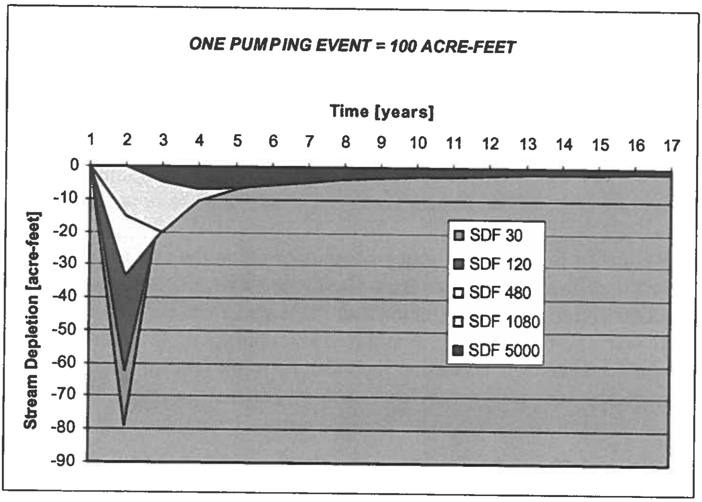

Figure 2. Assume one pumping event at 100 acre-feet; if the well is located at 120 days from the river, most of its impact on the river will occur in the first two years after the pumping event. If the well is located 5,000 days from the river, the most significant impact on the river will occur 4 years after the pumping event.

The USGS completed an extensive mapping of the South Platte in the 1970's and determined SDF values. Maps showing lines of constant SDF were developed and these maps continue to be valid and useful today for those areas mapped at that time. Other areas of the South Platte have never been mapped but additional work is being done by consulting firms in support of their client needs to predict the depletive effects of pumping. The SDF method is one of the most common methods used in these plans to predict stream depletion as well as stream accretion from ground water recharge.

REPLACEMENT WATER SOURCES

Newly formed well augmentation groups are making use of a variety of replacement sources. Because these water sources must replace ground water depletions at the proper time (often throughout the year), location, and quantity, it is necessary for these groups to have a diverse water supply portfolio. Some examples of water replacement sources that are used in the basin include:

(1) **Storage Water** - many companies have storage water rights in reservoirs, which may be changed through the water court and used for augmentation purposes. Augmentation sources in storage offer a degree of flexibility over other augmentation sources because they can be released from the reservoir on an as needed basis. For example, Union Ditch Company owns several shares in a local reservoir company which it plans to use for augmentation. Union may request the exact amount of water to be releases at the exact time that water is needed.

(2) **Senior Direct Flow Water** – many companies are in the process of purchasing direct flow water rights from shareholders within their own company or within other companies. Once purchased, these water rights can be changed through the water court and used for augmentation purposes. In order to meet the objectives of the State, it is becoming increasingly important for augmentation groups to actually own, rather than lease their replacement sources. This has real implications for agriculturalists, who find it difficult to compete with the high market price of water in the region.

(3) **Excess Augmentation Credits** – the water replacement portfolios for each augmentation group differs significantly. As such, there may be times when one group has developed excess augmentation credits that they can lease to other groups that are in need. Union and NCLPIC are two of several groups that have identified each other in their augmentation plans as sources of additional water supply.

(4) **Dry-up of Irrigated Land for Bypass** – it is not known at this time if the temporary dry-up of irrigated land for purposes of bypassing water supplies is an acceptable source of replacement water. The concept is that during times of drought, farms would dry-up all or a portion on their irrigated land. Water

previously dedicated for irrigation on this land would bypass the farm and become available for augmentation credit.

(5) **Retiming Wells** – ground water pumped from tributary wells can be a source of replacement water if the well is covered in an augmentation plan. Retiming wells are used to "retime" stream depletions. For example, a well group may pump their retiming well because they need replacement water in the river today, with the hope that they have water in the future to repay the retiming well depletions that are yet to occur in the river. Figure 3 shows a retiming well that is used to pump water into a spillway to the South Platte River. Because retiming wells do not provide a real source of replacement water (it is actually tributary ground water), they aren't a preferred replacement source; however they are commonly used.

Figure 3. Retiming well in operation. Water is pumped from the ground and is delivered to the river to cover stream depletions from irrigation well pumping. Sometime in the near future, stream depletions from the retiming well will occur in the river, and must be covered.

RECHARGE PLANS AND RECHARGE STRUCTURES

Another commonly used source of replacement water includes developing a new, junior water right for recharge. Both NCLPIC and Union filed for junior water rights in 2003 with the intent of diverting water from the South Platte River during wet periods and/or during the winter (whenever their new right is in priority). The water will be diverted into newly constructed recharge ponds located at varying distances from the river depending on the desired timing of the accretions. Water placed in the "recharge structure" ponds will be allowed to seep into the ground and will slowly move towards the river, where it will ultimately serve as augmentation credits. The IDS models can be used to determine the strategic location of these ponds to insure that recharge credits hit the river at the time needed to replace well depletions (Figure 4).

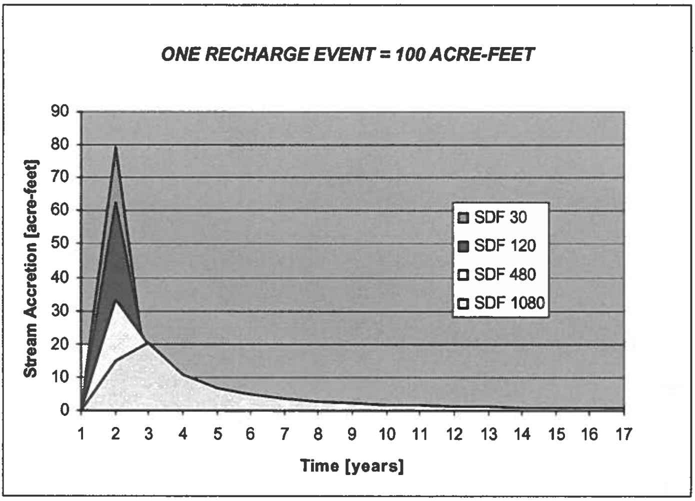

Figure 4. The concept of ground water recharge is essentially the same as ground water depletion, only in reverse. Recharge ponds can be located so as to strategically time recharge to the river.

PLAN ACCOUNTING

A significant component to the augmentation plan is real-time measurement, recording, and accounting. Plan operations must be reported to the State at least on a monthly basis and must include a daily accounting of well depletions and replacement activities in the river. The most accurate measurement equipment is required for plan monitoring and reporting activities. This degree of accountability is needed to insure other water right holders and the public that well pumping is not unjustly impacting the water supply in the river. Interestingly, the checks, flow measurement structures, gates, and SCADA that may be required for plan monitoring and reporting are also desirable from the standpoint of modernizing the canal system. This is proved to be a factor in both the Union Ditch and the New Cache La Poudre Irrigating Co. situations.

SUMMARY

Colorado's water supply is limited and, in many streams, over appropriated. Severe and unprecedented drought has aggravated an already difficult situation. Well pumping in the South Platte River basin has come to the fore as an issue and substitute water supply plans and well augmentation plans are receiving heavy scrutiny from objectors. Water court proceedings over the next few years will likely set law, rules, procedures, and impositions on all types of water rights.

So where is all of this likely to go? Likely future outcomes include:

- Increased scrutiny of all aspects of Colorado water rights.
- Increased reporting and administrative requirements imposed by the Colorado Water Court and the State Engineer's Office.
- Increased need for measurements, including real time measurements.
- Some agricultural wells will not be augmented, which results in all the related consequences and impacts on Colorado's agricultural economy.
- More difficult, time consuming, and expensive water court proceedings and challenges.
- More discord between conflicted interests without implementation of conflict resolution and negotiation elements into the process.

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WATER BANKING IN COLORADO: AN EXPERIMENT IN TROUBLE?

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ABSTRACT

This presentation reports on the progress and problems of the Arkansas River Basin Water Bank Pilot Program in Colorado. The term "water banking" has been used to describe a variety of ways of trading use of water; the legislature's choice in Colorado was a non-profit brokerage mechanism trading only stored surface water. This experiment in modifying traditional prior appropriation law reduces transactions costs and delays in transfers of water, to increase flexibility for the benefit of the holders of agricultural water. Such flexibility is expected to become increasingly desirable in conditions of scarcity and shifts from structural to non-structural approaches to supply. The Colorado experiment is described, to try to explain how a great theory with substantial appeal in principle has been so far socially unacceptable (as of the time of paper submission). The goal is to alert irrigation people to another case of social management being critical to success, regardless of technical charms.

PRESSURE TO MOVE WATER

The need for municipal water supply has dramatically increased with urban growth in the Western U.S., paralleling urbanization in the rest of the world (Western Water Policy Review Advisory Commission (WWPRAC) 1998, USDOA and USDOI "Water 2025"; Gleick et al. 2002). The legal background for problems in moving water under the prior appropriation system is well described elsewhere (WWPRAC 1998, NRC 1996, NRC 1992). The Colorado urbanization has already moved a great deal of water to cities, as USCID members and others will already know, with no known effective constraints on growth from water supply problems (Nichols et al. 2001). Meanwhile, adverse pressure on small agriculture in marginal areas is strong (see especially USDA Economic Research Service, many items, e.g. McBride 2003, and Agricultural Policy Analysis Center).

"WATER BANKING"

There are several uses of the term "water bank" (MacDonnell et al. 1994), including informal trading of rights to withdraw from a well-defined pool, as in the case of Snake River Plain operations or within Reclamation projects, or at the other end, suspension of legal hindrances and operations by a capitalized agency

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as in the California Drought Water Bank (Easter et al. 1998, Jercich 1997, Thompson in Anderson and Hill, Eds. 1997). The shared fundamental is reduction of the transactions costs of moving water, making it more like other resources. Because water is complex in externalities of use and necessity, moving it toward the purely economic realm ("commodification") is controversial (Brown and Ingram 1987, WWPRAC 1998). Economic theory of increasing welfare by moving resources to those uses with the highest value also suggests that non-market values and externalities should also be considered. Non-agricultural public interests in water uses may eventually use water banks, also. Salinity reduction may call for easier changes in water use, to decrease salt loading from deep percolation onto marine shales (Gates et al. 2002), and there may eventually be outlets for conservationist willingness-to-pay for riparian and wetlands habitat.

For agriculture, potential applications for climate information and seasonal forecasts are being identified (see website of National Ocean and Atmospheric Administration Office of Global Programs for updated research reports; Gleick 2000). In Colorado, response to forecasts is limited by inflexibility in water management and allocation (Wiener 2002, 2003, 2004). The "water bank" idea would allow responses to pre-season forecasts, in-season re-allocations, and well-informed multi-year interruptible supply contracts, or dry-year options plans to meet municipal supply firming goals with a higher value for water than farming during drought years. There may be connections between flexibility of management of the valuable water asset, and financial success in farming and capacity to intensify or adapt to new markets.

THE COLORADO CONTEXT AND EXPERIMENT

In the context of visible landscape changes, the impacts of large water transfers away from agriculture, and legislative rejection of growth management, the Colorado Governor's Commission on Saving Farms, Ranches and Open Space (2000), reached findings similar to polls (Fix et al. 2001) and national sentiment favoring agriculture and its land base (Hellerstein et al. 2002). Citizen approval of interruptible supply contracts (or "dry-year options") was also reported by city officials in 2001 and after. Drought-stimulated public discussion of water issues in 2002 and afterward has confirmed policy-making level acceptance of both agricultural preservation, and supporting changes in water law (e.g. Colorado Water Congress, Agricultural Outlook Forum, Statewide Water Supply Initiative meetings, news coverage).

Colorado's East Slope provides an interesting contrast between the South Platte Basin, which includes most of the Denver metropolitan area, and the Arkansas River Basin, which includes Colorado Springs, Pueblo, and the areas southward and eastward. In terms of agriculture, average field size is 37 acres in the Arkansas (1/4 1/4 section minus lanes) and 127 acres in the South Platte (1/4 section, minus area not covered with center pivot irrigation system) (Frasier et al., 1999). Agriculture was the source of 1.5% of South Platte income in 1990, but it was 7% of Arkansas Valley income, excluding Colorado Springs and its county, and if one also excludes the City of Pueblo, the farming counties that use Arkansas River water got 26% of their income from agriculture (Howe and Goemans 2003). Comparing the farming counties, net income per farm acre was $73 in the South Platte, versus $26 in the Arkansas (1990 and 1994 data combined; illustrative use only). Crop sales from the South Platte for 2002 were $414,500,000, versus $120,465,000 for the Arkansas (and adjacent ground-water using Baca County) (Co. Ag. Statistics Service.) on less than twice as many acres harvested (1997 Census of Ag. data, National Ag. Statistics Service).

In the South Platte, federal, municipal and private water projects import a substantial amount of trans-basin water from the Colorado River Basin. In Colorado only that amount of water which could legally be moved was exported, so it can be used "to exhaustion" in the area of destination (WWPRAC 1998, Corbridge and Rice 1999). The Northern Colorado Water Conservancy District, client for the Colorado-Big Thompson Project, provides shares of water without retaining ownership of return flows after the first use. These shares are transferable at will and almost no cost. This project provides an average of 270,000 A'/year – enough to support a market. This has likely worked in a cause-and-effect relationship with a high density of "plumbing" in the South Platte, increasing the physical transferability. The Frying Pan-Arkansas Project's client Southeastern Colorado Water Conservancy District retained ownership of return flows from an average import of 69,000 A'/year, perhaps not enough to establish a market alone. Except for re-allocation of project water, transfers in the Arkansas need water court adjudication, except under very limited or emergency conditions. Transactions costs have been very high (Howe and Goemans detail this comparison, 2003). The costs of moving water have affected the amounts moved, and the frequency of moves (Howe 2000, Howe et al. 1986) and very likely the parties to whom it is moved. Again following Howe and Goemans, with very low transactions costs, the size of transfers in the South Platte have been far smaller than in the Arkansas, and the number of agriculture-to-agriculture transfers for the study period examined (before the onset of the wet late1990s or the very dry recent period) was 34% of the total, and the volume of water moved was 26% of the total. In the Arkansas, with water court involved, agriculture-to-agriculture transfers for the same period were less than 2%, and most water transfers have been very large transfers to cities, often involving almost all of a ditch. The secondary social impacts have been notorious, including loss of farming, adverse impacts on ranching due to loss of local hay and feed production, leading to decreased local economic activity, decreased tax bases and government and school finance, and so through the economy. Howe (and colleagues, all references) and Weber (1990) have provided analyses of secondary impacts and the rationale for improved water markets.

The public concern with "dried up towns" has surged now and then, and reached an unusually high level in 2000 and 2001, ahead of awareness of the drought which peaked in 2002. That led to several more of the many attempts to legislate a requirement for mitigation of the economic impacts of large water transfers. So far, none of about 18 "mitigation" bills has passed, but there is persistent concern and will be more attempts (number widely used, e.g. Ann Montano Esq. at Colorado Ag. Outlook Forum, February 2004); this has helped maintain awareness and supported management innovation as well.

The legislature's explicit goals for the Arkansas River Water Bank Pilot Program included simplification and improved approval process for leases, loans, and exchanges, including interruptible supply agreements for stored water (note "stored" limitation), reducing transactions costs, increasing information available, and helping agriculture realize value of water without forcing severance from the land (HB01-1354, 2001, C.R.S. 37-80.5-101 et seq.; amended HB 03-1318, 2003).

There are environmental implications from moving water, both beneficial and adverse to the area of origin. In the case of Boulder County (Crifasi 2002), only 1 percent of water body surface is "natural"; the rest is agricultural or municipal in origin. And, 18 to 20% of riparian vegetation in the study area is along ditches and canals. The portion of local ecologies supported by water distribution and irrigation "inefficiency" may be very high farther away from the mountains, where tributary inflows to main stems may be largely ephemeral. Troublesome impacts on soil and weed infestations in formerly-irrigated areas not intensively managed are also feared; in the case of the Rocky Ford Ditch "first half" sale, concluded in the 1980s, only 12% has been claimed fully re-vegetated (Southeastern Colorado Water Conservancy District Board meeting 15 April 2004). But moving water away from some lands may be a great benefit where deep percolation is dissolving salts from underlying marine shales, with return flows accumulating very high salinity. The lower Arkansas often exceeds 4,000 mg/l, with localized higher concentrations in the water table (Gates et al. 2002). This lowers crop yields, even with high water applications to flush root zones, and increases costs for drinking water treatment enough that efforts are underway to secure federal funding for a drinking water conduit parallel to the River. There is substantial public interest in improved flexibility of water management.

Why, then, does something so apparently appealing seem to be in trouble? As Dean Joan Dusky has said, "the field of dreams doesn't work! Even if you build it, they won't come." It takes much more than a good theory, and a good institution; these are necessary but not sufficient.

THE INSTITUTIONAL DEMONSTRATION

The staffs of the Office of the State Engineer and the Attorney General worked hard to add the extra tasks called for by the legislation, including a series of public meetings and several additional appearances related to the water bank rule-making. The radical departure from Colorado's water law was opposed by many water leaders, and there was widespread expectation that the rules would be instantly litigated and perhaps never go into effect (interviews by author and informal conversations). Ditch companies in particular were often privately negative, but officially non-committal, which was in effect negative. Outreach and inquiry led to some reconsideration, but on the formal record, only one company endorsed more flexible water management; it subsequently made an innovative lease deal with an out-of-basin city, under later new legal authority. Some major objections were made on principle, and some by a group that perceived themselves as vulnerable to adverse impacts from mismanagement, judging by the public rule-making hearings. The major compromise reached was delay and use of a notification list for any transactions, and further delay if there is objection. The normal "spot market" idea was defeated, losing the use of the water bank for in-season re-allocations, and leaving the fastest transaction in 3 or more months, instead of the days involved in the Northern District and other working water bank operations, but this is still improvement over delays in years. The compromise averted litigation and accomplished rule-making on the legislature's timetable. Subsequently, the Southeastern Colorado Water Conservancy District agree to be the water bank operator, and a website for the electronic bulletin board was formally made operational January 2003 (www.coloradowaterbank.org).

Unfortunately, the legislature undercut a major potential use of the Water Bank in 2003, yielding to an arguably misinformed push against further out-of-basin transfers, though it also endorsed a shrunken concept by allowing it to be tried statewide (HB 03-1354). There is a fundamental contradiction between those who demand the right to sell their asset ("it's my 401k!") versus those who want agricultural water to stay in the areas of origin. The water bank, had it not been altered, should have demonstrated the potential for the kind of long-term deals with out-of-basin transferees that might well have provided the highest steady income, from long-lived interruptible supply contracts, while keeping the water rights on the farm and helping to capitalize modernization and intensification. Public sentiment against out-of- basin transfers was stalemated by the farmers' property rights claim of right to sell, and the cities' claims of right to buy, and the first compromise intended by the legislature was modified. Ironically, the legislature also expanded authority to make short-term (up to ten years duration) dry-year leases, thus helping cities get supply but again defeating long-term stability and markets in interruptible supply (HB03-1334). The new state-wide water-bank authority also retained the 2007 sunset provision, defeating long-term deals. And, the requirement to report to the legislature in 2005 is still in place.

So far, as of July 2004, there have been no transactions, while rentals are active in the Northern District (see http://www.ncwcd.org/hot_topic/rentalwater.asp). And, permanent sales of water rights out of agriculture are still unmitigated in impacts, and large ones threatening thousands of acres of "dry-up" impend.

THE EXPERIMENT AS AGRICULTURAL INNOVATION – THE MISSING PARTS OF THE PUZZLE

Important agricultural innovations in the U.S. have been made available by a combination of cooperative extension services and manufacturer sales communications for more than a century (Rasmussen 1989, Nowak 1992, Seevers et al. 1997, IPCC 2001, Rogers 2003). Traditional delivery has both involved potential users and provided localized demonstration of the benefits and applications of the innovation. Such innovations demand respect for the intended beneficiaries (Wiener 2002) in ways not necessarily obvious here, given the history of participatory demonstration. We blew it, in this case. Regarded as an agricultural innovation, none of the usual steps were taken to develop, communicate, and demonstrate the water bank innovation. Rogers (2003) provides the leading synthesis on diffusion of innovations. He has distilled five attributes of an innovation that affect adoption. On "relative advantage", the Water Bank should rank well, if it were understood. On "compatibility", however, it ranks low; uses are not well understood. "Complexity" is actually low, but limitation to internet makes it look worse than it is. "Trialability" is actually much higher than potential users often thought; misunderstanding was rife. And "observability" has been missing, since no one has tried it, and the first simple models showing operations are just now in progress. Bad program design!

Specific to agricultural innovation, there are critical contextual issues which affect interest, understanding, acceptance and adoption. Seevers et al. (1997) offer the comic mnemonic "SHEEEP", which can be briefly used to illustrate how poorly the ground was plowed in this case. Social factors include major events, demographics, and such. For example, "graying farmer" problems are relevant; one county commissioner said that "these guys don't use internet; they never will." There was no funding for the water bank, so no capacity to provide outreach service beyond the generosity of the District. Historical factors are very important: the big water transfers in the past were huge social injuries compounding earlier loss of the sugar beet business, begun in the West in the Arkansas Valley, and shrinkage of the melon market. The cities are widely and not unreasonably regarded as the enemy of the rural, and the persistent refusal to allow mitigation bills convinced many that the water bank was just another device to take the water. Outreach and explanation, let alone demonstration, were limited to only the initial public meetings for rule-making. Economic issues are important: the long decline in agriculture and related businesses has disheartened many, and the big water transfers have dried-up thousands of acres fields and little towns, as others struggle to keep some businesses going. Long-term improvement or at least moderation of the changes is an important goal, but the source of the innovation was perceived to be the source of the problem, not the solution. Educational achievements are not a problem. Emotional issues are critical here, because the loss of water to out-of-basin transfers is literally the loss of the way of life for many, and the loss of the future for some places. The kinds of economic activity possible after irrigation are not the same, according to people in the Valley, and in the words of a very influential person, taking the water away is "just plain evil." The emotional power of the loss of farms and families is enormous. Ironically, that power is probably the single biggest force working against using the water bank. The irony is that yielding to this fear apparently caused the legislature to revoke authority for out-of-basin transfers, which made the most lucrative likely long-term support for farmers unavailable (in-basin cities are well-supplied). The second irony is that strident association of the water bank with "just another scam to steal the water" (e.g. dozens of newspaper editorials against water transfers) seems to have deflected attention away from possible in-basin transfers which could provide firmer water supply for higher-intensity farming and recapitalization help for the transferors. For instance, organics are growing 20% per year (Dimitri and Greene 2002), but moving water to organic-certifiable soils takes the high-cost slow process in water court, without a water bank to cover the first few years. Political issues are also critical, since the moving of water is a political act in conditions of severe imbalance between supply and demand; and it has profound political effects where the secondary impacts are so important. The rural-urban split in Colorado is based in this, and it is not alleviated by the failure to find, enact, and use better management. Future economies of any kind may depend on keeping enough water, as amenity for the region as well as for use as an input to production, even of hobby-based and tax-benefit-seeking small acreage "farms", which are a very fast-growing part of the rural landscape.

Given the enormous resentment of losing water, and the identification of new management with the old goals of just taking it away without any mitigation of impacts, it seems reasonable to expect that a substantial effort to illustrate the differences between old and new will be needed; so far, well-informed people have simply denied them. Given that this is an agricultural innovation, at base, why expect success without any of the traditional demonstrations and local applications? The social part of this process has only begun, and it is now very important that the report to the legislature may be done before any of the appropriate steps to try the experiment are undertaken. Early focus on the institutional and legal issues overlooked the human and social realities, to the frustration so far of an important improvement in flexibility in water management.

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ESTIMATING CONSERVABLE WATER IN THE KLAMATH IRRIGATION PROJECT

Beau Freeman[1]
Charles Burt[2]

ABSTRACT

In 2001, irrigation water was withheld from the majority of farms in the U.S. Bureau of Reclamation Klamath Project to provide in-stream flows for fish species listed as "endangered" or "threatened" under the Endangered Species Act (ESA). The subsequent controversy and pleas for emergency action highlighted a wide gulf in the technical understanding of the actual hydrologic and hydraulic processes that occur in the Klamath Basin.

A multi-year hydrologic assessment was performed to determine the precise destination, volume, and timing of surface and subsurface water flows throughout the Klamath Project. Confidence intervals were assigned to each water origin or destination component based on a systematic field examination of the physical processes used to measure or estimate various hydrologic values. The primary conclusion of the investigation was that significant amounts of irrigation water cannot be made available to the Klamath River by traditional water conservation activities.

The irrigation community in the Klamath Project faces critical future challenges, which the existing internal processes and physical infrastructure are incapable of dealing with successfully. This will require significant irrigation modernization to improve the precise control and monitoring of flows at different levels of the system, especially on a real-time basis, and thus provide excellent water delivery service to individual irrigation districts and water users.

INTRODUCTION

Background

The Klamath Project is one of the earliest federal reclamation projects developed and operated by the U.S. Department of the Interior's Bureau of Reclamation (authorized in 1905). The Klamath Project is located in southern Oregon and northern California and provides irrigation water to over 200,000 acres of

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farmland, as well as water supplies for important national wildlife refuges and wetlands.

The issues in the Klamath River Basin are extremely complex with many different interests being represented, many of which have conflicting views over the desirable outcomes. In part this is a result of different philosophical opinions on various issues (endangered species, tribal responsibilities, economic feasibility of certain types of agricultural production, habitat restoration, etc.). Arguments over the reasonableness of particular claims to the Basin's water resources will eventually be settled in courts or through legislative actions.

This apparent complexity and controversy increases the need for pursuing practical solutions based on information that is sound from scientific, economic, and engineering perspectives. However, the authors' initial impression was that in addition to the desire for different outcomes, there existed a wide gulf in the technical understanding of the actual hydrologic and hydraulic processes that occur at various locations over time in the Basin.

This can be considered a crisis of information. Although the Klamath Project itself, the wildlife refuges, various aspects of the ecosystem, etc., had been studied for many years, there apparently was no clear(er) picture of issues such as the realistic potential for water conservation (either on-farm or at the district level), or the actual irrigation efficiency of the Klamath Project as a whole, as well as the efficiency of individual irrigation districts within the Project.

Study Features

To address the need for accurate and reliable information, a comprehensive hydrologic assessment was undertaken in the Klamath Project. The results were intended to provide decision makers and stakeholders with a scientific framework for understanding the realistic potential for water conservation from agricultural land and wildlife refuges, as well as for management of the water resources for other purposes such as improving water quality.

The investigation was comprised of three components:

1. Multi-year water balances at different hydrologic levels in the Klamath Project with specific estimates of the uncertainty associated with each measurement
2. An examination of the physical infrastructure design, internal operations rules, communication systems, water measurement, and management practices of the Klamath Project
3. An assessment of specific modernization recommendations focused on irrigation water management

The hydrologic assessment incorporated:

- Monthly water balances of the volumes and destinations of irrigation water and precipitation
- 30 separate surface water and groundwater flow components
- A study period of 1999 to 2001
- A division of the Upper Klamath Basin into five hydrologic subregions to facilitate a more accurate assessment of the historic records and internal water control processes
- A systematic field examination of the physical processes used to measure or estimate various hydrologic values that appear in various reports
- Assignment of appropriate confidence intervals (estimate of uncertainty) to each water origin or destination component
- A ranking of the water balance components as a measure of their relative contribution to the accuracy of the final values.

The area of investigation was geographically restricted to the Upper Klamath River Basin, particularly the area defined by the Klamath Project. While it was recognized that the quantity and quality of available water in the Klamath Project is influenced to a great extent by the hydrology and water operations in the other sub-basins upstream of the selected area of investigation, this study was limited to the region shown in Figure 1.

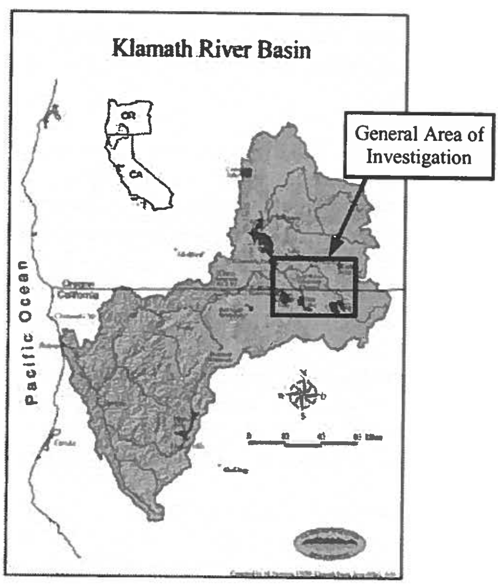


Figure 1. Area of investigation in the Upper Klamath River Basin

CONCEPTUAL APPROACH

The Klamath Project presents some unique challenges in terms of assessing project performance. A necessary prerequisite for examining a project with such extensive geography and operational complexity is a set of standardized investigative procedures. The conceptual approach used in this investigation was intended to gain a better understanding of the precise destination, volume, and timing of surface and subsurface water flows that occur throughout the Klamath Project (i.e., water balance).

A related topic is an assessment of the operational processes that are used in conveying and delivering irrigation water throughout the Klamath Project, consisting of activities such as the manipulation of hydraulic control structures, decision-making procedures, monitoring techniques, record keeping practices, and communication systems. These are broadly described as the "internal processes" of the Klamath Project.

A synthesis of the water balance accounting, recognizing uncertainties, with an understanding of the internal processes allows one to quantify the realistic potential for meeting objectives, in addition to prioritizing investments at different levels in the system, including project facilities and on-farm programs. This allows one to identify specific actions that can be taken while taking into consideration the resulting effects to the rest of the system.

Our conceptual approach has three components, which are interrelated and follow a logical order. In simple terms, this investigation attempted to answer the following set of questions:

- ***What water is potentially available to meet a quantifiable objective?*** What are the water quantities, and timing of surface and subsurface flow paths at different hydrologic levels in the Klamath Project?
- ***Can the available water be manipulated and how?*** What are the most feasible and cost effective options for changing the current physical control and management systems that control the water as it moves through the Klamath Project in order to meet a selected quantifiable objective?
- ***What will be the impact of making "x" change at "y" location at "z" time?*** What is the potential impact of a particular water conservation activity or change in operations, in terms of the relative water quantity, quality, and timing of the various flow paths in the Klamath Project?

This investigative methodology is different from past studies in the Klamath Basin, with important implications. Figure 2 summarizes aspects of our approach of determining the appropriate area and level for targeted investments.

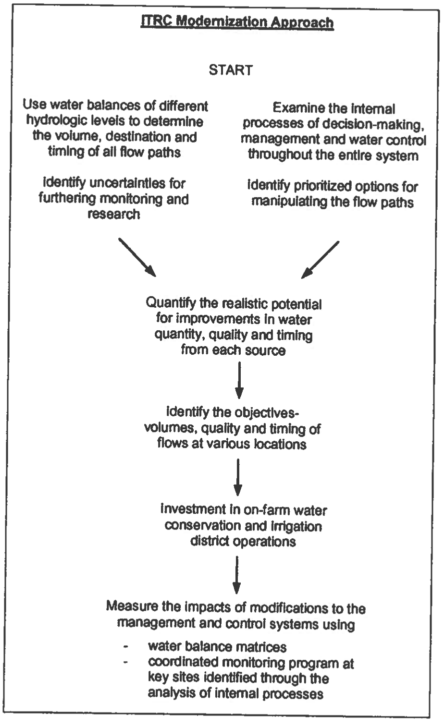


Figure 2. Recommended approach to addressing Klamath Project water-related issues

KLAMATH PROJECT WATER BALANCE 1999-2001

A water balance was computed for the Klamath Project for the years 1999 to 2001. The water balance provides an accounting of all surface and groundwater water volumes that entered or left the boundaries of the irrigation districts and wildlife refuges on an annual basis (Burt 1999). The quantitative assessment incorporated detailed information on the hydrology, climate, irrigation district operations, water measurement, hydrogeology, and farming practices of the Upper Klamath Basin. The final hydrologic quantification is composed of over 30 separate flow components, each with an assigned confidence interval to reflect the estimated accuracy of the reported value.

The fundamental hydrologic relationship of water balances is that the volume of water entering the defined 3-dimensional boundaries is equal to the volume of water leaving the same boundaries, plus any change in storage. Thus, the water balance for the Klamath Project was computed using the following methodology:

Inflows = Outflows + Change in Storage

Inflows

\+ Surface water diversions

\+ River and tributary flows

\+ Precipitation and snowfall

\+ Groundwater inflow discharged at Bonanza Springs

Outflows

\- Total consumptive use

\- Surface water discharge

Change in Storage

\- Change in surface water storage

\- Change in root zone storage

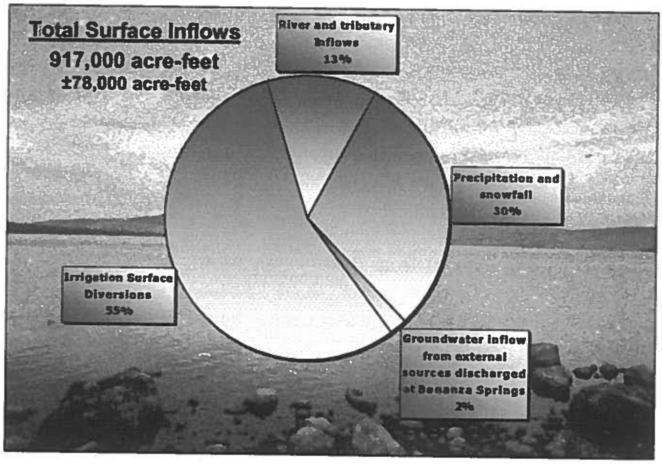
\- Change in groundwater storage

= **Net lateral groundwater inflow/outflow** (closure term)

Each of the major flow paths is comprised of individual flow components. For example, the consumptive use term is the sum of:

- Agricultural fields evapotranspiration
- Refuge wetlands evapotranspiration
- Evapotranspiration from canals
- Evapotranspiration from drains
- Evaporation from reservoirs, lakes, streams, and creeks
- Evapotranspiration from urban areas
- Evapotranspiration from undeveloped land

Total average (1999-2000) inflow to the boundaries was approximately 917,000 acre-feet while total outflow was approximately 1,001,000 acre-feet as shown by the simple illustration in Figure 3. Surface water diversions and evapotranspiration from agricultural fields are the largest single inflow and outflow components, respectively. Confidence intervals were assigned primarily on the basis of field visits to each of the surface monitoring stations. The inflow confidence intervals ranged from 7 to 9%, which is equivalent to a margin of error of about ±78,000 acre-feet in 1999 and 2000. The outflow confidence intervals ranged from 12 to 18%, which is equivalent to a margin of error of about ±125,000 acre-feet in 1999 and 2000.



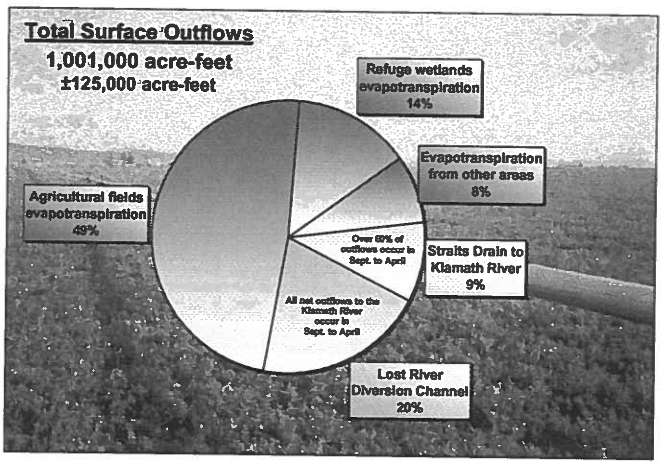


Figure 3. Surface water balance of the Klamath Project (avg. of 1999-2000)

In 2001, surface diversions to the Klamath Project were curtailed by over 60%, while irrigated agricultural acreage in the Klamath Project was reduced by about 27% based on remote image processing. The corresponding reduction in the evapotranspiration from agricultural fields was about one-third, compared to an average of the two previous years.

The water balance closure term was the net lateral groundwater inflow/outflow to the boundaries. Taking into account the annual change in surface water storage and the change in groundwater storage, both in the root zone and the aquifer system, the apparent 3-year average net lateral groundwater inflow to the area was about 31,000 acre-feet. However, there is more than 100% uncertainty in the closure term of net lateral groundwater inflow/outflow, as evidenced by the closure confidence intervals of 1.0 or greater. Thus, the magnitudes of the confidence intervals of the annual closure terms mean that the actual net recharge or discharge contribution of lateral groundwater flow is uncertain.

Key Conclusions

There are three key conclusions from this investigation.

1. Significant amounts of irrigation water cannot be made available to the Klamath River by traditional water conservation activities such as canal lining and improved field irrigation efficiencies.

   Almost all on-farm and district conveyance inefficiencies are recycled internally within the project, or returned back to the Klamath River. Figure 4 shows the volume of surface irrigation water diverted into the Klamath Project versus the evapotranspiration of irrigation water from agricultural fields and refuge wetlands.

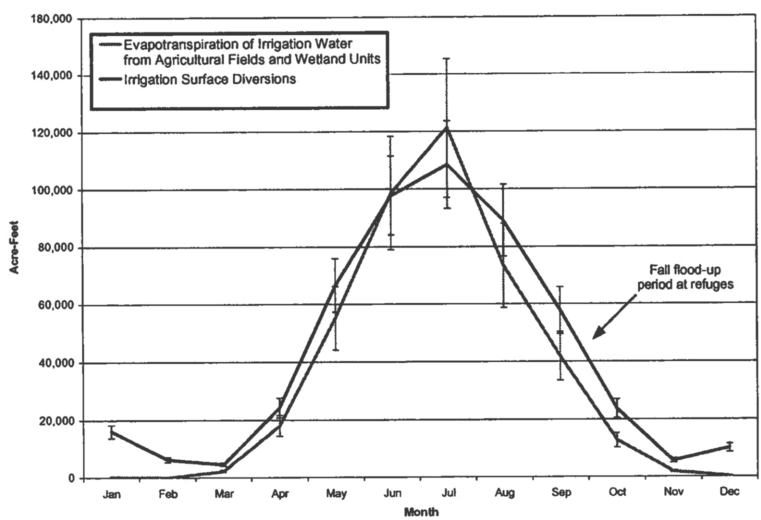


Figure 4. Irrigation surface diversions and the evapotranspiration of irrigation water from agricultural fields and refuge wetlands in the Klamath Project area of investigation (avg. of 1999-2000). [Vertical bars indicate confidence intervals of data.]

2. Because almost all of the diverted surface irrigation water is consumed as evapotranspiration, increasing the flows to the Klamath River during critical late summer months can only be accomplished by actions such as one or more of the following:

    - Decreasing evapotranspiration through a reduction in irrigated agricultural acreage or irrigated wetlands acreage
    - Replacing surface irrigation water with groundwater
    - Increasing surface storage of irrigation water

3. While a primary issue at the moment is restoring endangered fish populations and habitats in the Upper Klamath Basin, the irrigation community in the Klamath Project faces critical future challenges that the existing internal processes and physical infrastructure are incapable of dealing with successfully. Example future issues that have already arisen in other irrigation projects, and that can have profound impacts in the Klamath Basin include:

    - Total Maximum Daily Loads (TMDLs) in rivers, streams, and drainage canals
    - Proposed electricity rate hikes in 2006. Current electricity rates in the Klamath Project are among the lowest in the U.S.
    - The ability to increase crop yields and crop qualities
    - Efficiency of farm fertilizer practices
    - Possible changes in water law that would require verified deliveries of specified volumes of water per acre, equitably distributed to turnouts within irrigation districts
    - Possible changes in water law and rights that would allocate specific volumes and flows to each irrigation district, with penalties for excess diversions. Although this may make no sense from a project-wide water conservation standpoint, it would have an impact on in-stream flows downstream of diversion points.

Priorities for Improving Future Water Balances

The relative importance of the accuracy of each water balance component was ranked to determine priorities for improving future water balances and hydrologic investigations of the Klamath Project. A variance analysis of the water balance volumes provides a general indication of the influence of the accuracy of each component on the accuracy of the overall water balance.

Table 1 shows the Klamath Project water balance components with a relative importance of uncertainty of more than 0.5%. The combination of the evapotranspiration volumes from agricultural fields and refuge wetlands together accounted for about 60% of the total variance.

Table 1. Ranking of the relative importance of the uncertainty of various overall water balance components (above 0.5%)

Water Balance Component	Relative Importance[1]
Agricultural fields evapotranspiration	55%
Ady Canal	16%
Lost River Diversion Channel (inflow/outflow)	15%
Refuge wetlands evapotranspiration	5%
North Canal	3%
Straits Drain	3%
Precipitation	2%
A Canal	0.6%
Evapotranspiration from undeveloped land	0.5%

[1] Based on 1999 and 2000 variance analysis

The relative importance gives an indication where further investment is required to improve the accuracy of a water balance. One cannot evaluate the significance of the known accuracy of a single water balance component based solely on the assigned confidence interval. Take, for example, the estimate of the annual change in groundwater storage in Table 1. This component had an assigned confidence interval of 0.25, meaning that the change in groundwater storage was only known within ±25%. However, the change in groundwater storage only had a 0.0001% impact on the accuracy of the final values in the water balance. This may be considered negligible when compared to the overall accuracy of the water balance. This further indicates that additional investment would be more beneficial directed towards improving the accuracy of other water balance components with a higher relative importance (e.g., better evapotranspiration estimates from upgraded/expanded weather station networks and more accurate information on irrigation practices and crop related factors).

SUMMARY

The water balance results indicate that on-farm modernization efforts will have minimal impact upon Klamath River flow quantities or timing of those flows, because of the vast system of reuse and re-circulation that exists within and between irrigation districts in the Klamath Basin. There also appears to be only a small lag time between application of irrigation water at one location and the reappearance of excess application (in the form of return flows) elsewhere.

Even though the primary focus at the present time is on restoring endangered fish populations and habitats in the Upper Klamath Basin, the irrigation community in the Klamath Project faces critical future challenges that the existing internal processes and physical infrastructure are incapable of dealing with successfully. This will require significant irrigation modernization to improve the precise control and monitoring of flows at different levels of the system, especially on a real-time basis, and thus provide excellent water delivery service to individual irrigation districts and water users.

This project was funded by the United States Bureau of Reclamation, Mid-Pacific Region, Klamath Basin Area Office, through a technical services agreement with the ITRC.

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SOCIO-ECONOMIC IMPACTS OF LAND RETIREMENT IN WESTLANDS WATER DISTRICT

Thaddeus L. Bettner[1]

ABSTRACT

Westlands Water District (Westlands, or the District) in California includes more than 560,000 irrigated acres of diversified crops on some of the most productive soil in the world. Land retirement has been proposed as a solution to two serious problems confronting the District: inadequate drainage on lands overlying shallow groundwater, and insufficient and increasingly unreliable water supply.

Large portions of the west side of the San Joaquin Valley are affected by salinity and drainage problems. This affected area includes approximately 300,000 acres of the District's farmland. The U.S. government has long been aware of these problems and congressional authorization of the San Luis Unit facilities mandated drainage service as part of this project. When Westlands entered into a water supply agreement with the U.S. Bureau of Reclamation (Reclamation), the provision of drainage service was expressly included as a contract term. Although Reclamation has studied the issue for many years, the drainage service options identified are extremely costly and their effectiveness is uncertain.

Land Retirement could address two of the District's most significant problems, those being drainage and water supply. But the decision to accept this proposal would not only affect the District farms. In addition, communities, employees, and businesses depend on the District's agricultural economy. In order to help the District make an informed decision on land retirement, Westlands completed an economic impact analysis.[2]

INTRODUCTION

Westlands Water District

The lands that comprise Westlands were first farmed during California's Gold Rush. Irrigated agriculture began in 1915, and by 1942, landowners had organized to develop a water supply system. Westlands was formed in 1952 to serve agricultural water users on the west side of the San Joaquin Valley. In 1968, the San Luis Canal was completed and water deliveries began under a contract with Reclamation.

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[2] "Analysis of Economic Impacts of Proposed Land Retirement in Westlands Water District", Westlands Water District, May 2003.

Today, Westlands is the largest agricultural water district in the United States, with more than 560,000 acres of diversified crops on some of the most productive soil in the world. Farms within Westlands produce $1 billion worth of food and fiber per year. This translates into $3.5 billion in farm-related economic activity, nearly one-third of the $12.5 billion generated by the agricultural-based economy of Fresno County.

In addition to the farms within Westlands, several communities depend on the District's agricultural economy. These include the towns of San Joaquin, Tranquillity, Huron, Firebaugh, Mendota, Kerman, and Coalinga. The location of Westlands and the surrounding communities are shown in Figure 1. This figure also shows the region within Westlands that is affected by poor drainage.

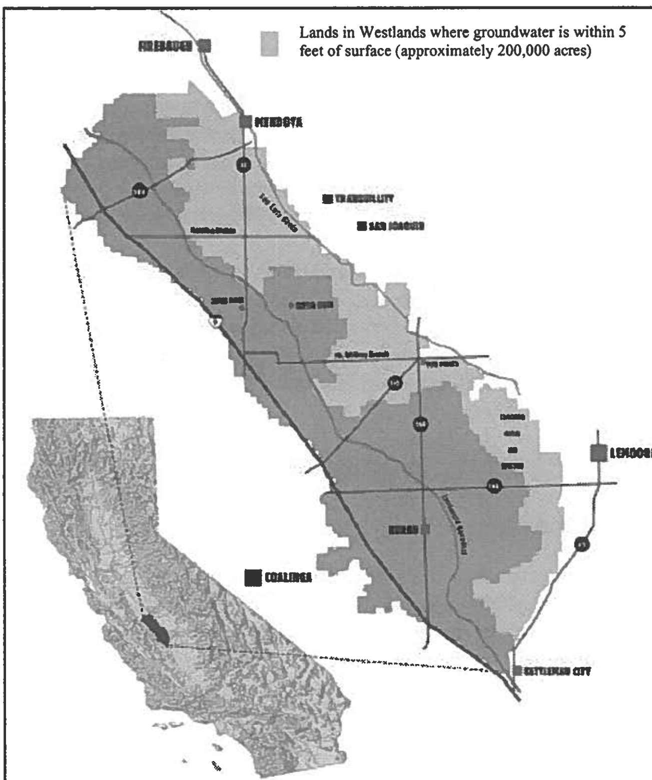

Figure 1. Map of Westlands and Surrounding Communities

Water Supply

Westlands has experienced a dramatic reduction in the amount of water it receives from the Central Valley Project (CVP). Since 1991, Reclamation has reduced water deliveries to Westlands to the point where today, the District can expect to receive about 65 percent of the water supply specified in the original contract in a normal hydrologic year. Due to the implementation of the Central Valley Project Improvement Act and other environmental regulations, Westlands has had to bear the brunt of reductions in water deliveries resulting from decisions to protect the environment of the Bay/Delta region. Table 1 provides historical CVP allocations to Westlands, water year type, and acres fallowed. Figure 2 shows the drought period of 1986-1993 with the lighter columns depicting the water allocation during this period assuming pre-1990 state and federal regulations relating to the

Table 1. CVP Contract Deliveries and Acres Fallowed in Westlands

Year	% of Contract Delivered	Year-Type	Acres Fallowed
1994	43%	Dry	75,732
1995	100%	Wet	43,528
1996	95%	Wet	26,754
1998	100%	Wet	33,481
1999	70%	Wet	37,206
2000	65%	Above Normal	46,748
2001	49%	Dry	73,802
2002	70%	Below Normal	94,557
2003	75%	Above Normal	76,654

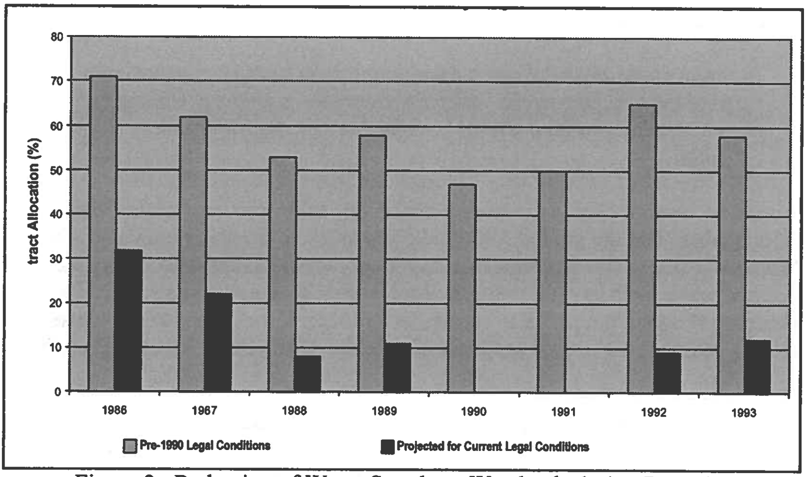

Figure 2. Reduction of Water Supply to Westlands during Drought

operation of the CVP. The darker columns depict what the deliveries would have been for that period from the CVP under regulations currently imposed on the project. The reductions range from 40% to 50%.

Although farmers in the District have improved irrigation efficiencies and the District has implemented a supplemental water purchase program, the reduction in CVP water deliveries has reduced the average quantity of water available per irrigated acre in the district. This has limited farm management options, increased farmers' financial risk, and made planning more difficult. Farmers increasingly rely on supplemental water supplies, including groundwater and water transfer purchases. Overdraft of the aquifer and severe subsidence in some parts of the District has made long term pumping of additional groundwater infeasible. Water transfers are becoming more costly and more difficult to obtain as competition for limited supplies intensifies across the state.

The water supply outlook for Westlands is not promising. It is unlikely, that in the near term, Westlands CVP contract supply will increase, groundwater pumping has already exceeded a sustainable level, and supplemental water purchases are becoming increasingly expensive. Over the long term, less reliable and more expensive water will reduce district farm revenues, limit cropping choices, and erode land values. Ultimately, marginally productive lands may be removed from cultivation due to insufficient or too costly water supply.

Drainage

Large portions of the west side of the San Joaquin Valley are affected by salinity and drainage problems. The Final Report of the San Joaquin Drainage Program stated the following:

> *Inadequate drainage and accumulating salts have been persistent problems in parts of the valley for more than a century, making some cultivated land unusable as far back as the 1880s and 1890s."*[3]

A shallow layer of clay under some parts of the Valley prevents water from filtering deep into the ground. With no place to drain, the water builds up – or "perches" – above this impermeable clay layer. Problems associated with the perched water table have been further exacerbated by the region's soils. The Drainage Program's report also stated that soils on the western side of the valley are derived from the marine sediments that make up the Coast Range and are high

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[3] San Joaquin Valley Drainage Program (1990), "A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside of the San Joaquin Valley: Final Report," U.S. Department of Interior and California Resources Agency.

in salts and trace elements that occur in a marine environment. Irrigation of these soils has dissolved these substances and accelerated their movement into the shallow groundwater. As the salty water rises to the surface, it affects the roots of crops, reduces yields, and eventually makes the land unproductive.

The federal government was aware of drainage problems in the Westlands area before the District was formed. Congressional authorization of the San Luis Unit of the CVP in 1960 also mandated construction of an interceptor drain to collect irrigation drainage water from the service area and carry it to the Delta for disposal. When Westlands entered into a water supply agreement with Reclamation, the provision of drainage service was expressly included as a contract term.

Construction of the interceptor drain began in 1968, and by 1975 the initial stages comprised 85 miles of the main drain, 120 miles of collector drains, and the Kesterson regulating reservoir. In 1983, the U.S. Fish and Wildlife Service recorded high incidences of mortality and deformities among waterfowl in Kesterson Reservoir. These were believed to be the effects of toxic concentrations of selenium in the drain water. The reservoir was closed to agricultural drainage water in 1986 and Westlands and other districts served by the San Luis Unit have been without drainage service since that time.

Nevertheless, the U.S. government remains obligated by law to provide drainage services to Westlands as specified in the original supply contract. In February 2001, the 9th Circuit Court of Appeals affirmed that, "The Department of the Interior must act to provide drainage service. The Bureau of Reclamation has studied the problem for over two decades. In the interim, lands within Westlands are subject to irreparable injury caused by agency action unlawfully withheld."

The issues that the Reclamation must deal with to provide this drainage service have become more challenging and costly. Environmental restrictions have made the original drainage disposal strategies less tenable. Researchers have identified several potential alternative drainage service strategies including treatment of agricultural drainage water, deep-well injection and use of evaporation ponds; however, all are costly and their long term effectiveness is unknown.

Agricultural Production

With the addition of irrigation water, the climate and soils within Westlands allows for the production of a rich and varied mix of agricultural crops. Prior to the delivery of CVP water, Westlands farmers primarily grew cotton, wheat and barley, with some vegetables. Over time cropping patterns changed, with increasing acreages first in truck crops (vegetables and melons) and more recently in orchards and vineyards. Westlands' farms now produce over 60 different crops, double cropping on some acreage when sufficient water is available. The

District produces nearly 30 percent of the state's processed tomato crop and over 20 percent of its cotton. Table 2 summarizes the major categories of crops grown in the District in 2001 and the approximate value of those crops.

Table 2. Cropping Patterns and Crop Value within Westlands in 2001

	Total Acres	Total Value ($000)
Cotton	188,569	$215,211,980
Grain/Field	87,878	$66,109,633
Orchard	46,166	$125,156,062
Row*	80,177	$284,089,451
Tomatoes	85,122	$150,709,329
Other	64	Not Available
Fallow	73,802	$0
Grand Total	561,788	$841,076,455

The cropping patterns differ between the shallow groundwater region and the remainder of Westlands acreage. In general, acreage in the shallow groundwater region is more likely to be fallowed or to grow lower valued crops (field/grain, cotton). While 32 percent of Westlands' acreage is affected by shallow groundwater, only an estimated 21 percent of crop value is produced on this acreage.

LAND RETIREMENT

Proposal

Following the recent 9th Circuit Court of Appeals decision affirming the government's obligation to provide drainage, U.S. government representatives approached Westlands with a proposal to remove up to 200,000 acres of drainage-impacted lands from production as an alternative to providing drainage service. Westlands viewed this proposal as a potential opportunity for solving the dual problems of drainage and worsening water supply reliability.

Currently, the general outline of the land retirement proposal is as follows[4]:

- The U.S. Government would purchase up to 200,000 acres of drainage-impacted lands, permanently removing them from irrigated agricultural production. These lands would be owned by Westlands and managed as wildlife habitat or put to other beneficial uses. Westlands would manage

[4] The Land Retirement Proposal was generated by Westlands Water District and provided to the US Department of Interior, Bureau of Reclamation and other interested agencies.

the retired lands in ways compatible with continuing agriculture on the remaining farmlands.

- Westlands would receive a new, more reliable water-supply.
- The United States would be relieved of its obligation to provide drainage service to Westlands.
- As it has considered the proposal, Westlands has adopted a set of guiding principles it will use to evaluate the plan:
    - The plan must provide balanced benefits for all affected parties.
    - The plan must provide farmers a fair and reasonable price for their land, with values determined as if those lands had drainage services provided.
    - The program must be voluntary, involving only willing sellers.
    - No harm or loss of water should occur to any other Central Valley Project water user.
    - Third-party impacts must be identified and addressed.

Economic Impacts

To better understand the economic impacts, Westlands analyzed the short and long term differences between a no-action scenario, land retirement scenario, and drainage service scenario assuming that Reclamation provided drainage service to the District in a timely manner. The short term reflects the assumed conditions after the implementation of the land retirement proposal within two to three years. The long term reflects the assumed conditions in 2020.

Short Term. For the short term, the following key assumptions were made to develop the three scenarios:

- For the no-action scenario, Westlands has acquired lands within the District that are assumed not to be irrigated. District cropping patterns are assumed to be similar to harvested acreage in 2001, with those lands acquired removed from irrigation subtracted proportionately from crops currently grown in the shallow groundwater region of the District.
- For the drainage scenario, no provision of drainage is assumed to have taken place by this time. Therefore, the short term results for the drainage scenario are the same as for the no-action scenario.
- For the land retirement scenario, land within the shallow groundwater region is assumed taken out of production by proportionately reducing the crops currently grown in the shallow groundwater region of the District. Changes in cropping patterns in response to the greater reliability of CVP water supplies have not yet occurred.

Table 3 summarizes the estimated short term effects on the region. In the short term, farm revenues and income would be the same under the no-action and drainage scenarios, but both would initially drop as a result of the land retirement. These reductions would initially affect on-farm employment and income, and in turn other income and employment within the region. For the land retirement scenario, the table shows that the most significant effects are on agricultural production, employment and proprietor income. Employee compensation is estimated to change less than employment, because the major reduction in employment is in farm labor, which has lower average incomes than do other sectors. It should be noted that all of these changes are the same as or less than changes that have occurred in the past because of decreases in water supply or cyclical shifts in commodity prices.

Table 3. Short Term Economic Impacts Compared to No Action Scenario

Economic Measure	**Scenario**	
	Drainage	Land Retirement
Agricultural Production	No Change	-10.2%
Employment	No Change	-7.3%
Employee Compensation	No Change	-5.1%
Proprietor Income	No Change	-7.4%
Property Income	No Change	-1.9%

Long Term. The estimates for long term impacts are reported in Table 4. By this timeframe, the following conditions are assumed to have changed:

- In the no-action scenario, increased salinity has reduced the yield of crops in the shallow groundwater region. As a result, the only crops that are economic to grow within that region are cotton, alfalfa, hay and grains. The acreage acquired by Westlands identified in the short term scenario is assumed to remain out of production.
- In the drainage scenario, provision of drainage is assumed to have occurred by 2020 and to have restored fertility within the shallow groundwater region to equal that of the remainder of the District. This assumes that Reclamation has provided drainage service in a timely manner. The reliability of CVP water deliveries is the same as in the no-action scenario. The acreage acquired by Westlands is assumed to be returned to irrigation.
- In the land retirement scenario, CVP water deliveries are assumed to be increased. Model-estimated plantings in perennial crops, which were assumed to be less sustainable in other scenarios, are maintained as a reflection of the more reliable water supply in this scenario.

In all scenarios, the demand for fruits and vegetables is projected to steadily increase over time as a result of expanding international markets and shifts in consumer preferences. As a result of these changes, the economic situation of farmers in the District, and most of the local communities in and near the District, is estimated to be improved in both alternate scenarios over that estimated for the no-action scenario. Agricultural production, total employment and employee compensation are highest in the drainage scenario, reflecting the increase in irrigated acreage enabled by drainage service. However, farm sector proprietor and property income are lower in the drainage scenario than in the land retirement scenario due to the cost of drainage service, supplemental water supply, and water supply restrictions. Overall, regional income is predicted to be highest under the land retirement scenario.

Table 4. Long Term Economic Impacts Compared to No Action Scenario

Economic Measure	**Scenario**	
	Drainage	Land Retirement
Agricultural Production	+11.5%	+4.2%
Employment	+10.9%	+7.3%
Farm Sector	*+12.8%*	*+6.3%*
Non Farm Sector	*+8.2%*	*+8.7%*
Employee Compensation	+10.2%	+7.7%
Farm Sector	*+13.1%*	*+5.9%*
Non Farm Sector	*+8.4%*	*+8.8%*
Proprietor Income	+5.4%	+14.0%
Farm Sector	*+4.1%*	*+16.4%*
Non Farm Sector	*+8.4%*	*+8.4%*
Property Income	+6.5%	+12.5%
Farm Sector	*+4.3%*	*+17.8%*
Non Farm Sector	*+8.3%*	*+8.3%*
Total Income	+8.2%	+10.3%

Because of the differing assumptions, significantly different tradeoffs in production are demonstrated in each of the scenarios considered. Under the no-action scenario, lack of drainage within the shallow groundwater region progressively increases soil salinity. As a consequence, cropping choices become increasingly limited, crop yields decrease, and farm returns fall. Vegetable and fruit production, in particular, is constrained by soil salinity, thereby decreasing the regional demand for farm labor. Additionally, CVP supply constraints under this scenario would subject the region to significant swings in production. During dry periods, large amounts of acreage may be removed from production due to lack of water supply. In wet years, the opposite might occur. The boom-bust cycles associated with inadequate and unreliable water supply are likely to be very pronounced under this scenario.

Under the drainage scenario, production constraints associated with soil salinity are removed. However, the cost of drainage service and unreliable water supply combine to drive up farm production costs, and drive down farm returns. While the modeling results indicate higher levels of farm production and employment, they do not show a corresponding increase in farm returns. Although farm finances are improved relative to the no-action scenario, they remain tenuous both because of the cost of drainage and because water supply remains unreliable. As with the no-action scenario, the regional economy would be subject to large swings in production associated with water supply availability.

For the land retirement scenario, production costs are stabilized. However, this is achieved by removing a significant amount of land from irrigated farm production. For the lands remaining in production, drainage and water supply constraints are largely resolved. Under this scenario, farm output and employment is lower because of the land retirement, but farm and regional income is higher because of increased production of higher value crops and lower production costs. As a result, communities on the western side of the District will be positively affected by the retirement. Because the land retirement would also stabilize the District's CVP water supply, swings in farm production would be lowest under this scenario. Boom-bust cycles associated with water supply would be less frequent and of shorter duration than would be the case under the no-action or the drainage scenarios. The benefits of this production stability to the regional economy are likely to be significant.

In summary, regional employment is highest under the drainage scenario, regional income is highest under the land retirement alternative, and both of these options are improvements over the no-action scenario. Another important difference between the scenarios is that the no-action and drainage scenarios are based on average water supplies that are expected to exhibit wide variation, and would also exhibit sharp decreases in employment and income in dry years and sharp increases in wet years. The benefits of stability in the supply of irrigation water are far reaching. Over time, with a stable water supply the local economy can adjust to supply the level of services required. However, under the no-action and drainage scenarios the region would continue to experience boom and bust cycles induced by the wide variations in water supply from the CVP. In addition, such loss of jobs resulting from periodic water shortages would be region-wide, not concentrated on the eastern side of the District.

CONCLUSIONS

Westlands Water District completed a study in recognition of the potential for impacts as a result of land retirement and to assist the District, local communities, landowners and water users and the United States to make informed decisions concerning land retirement. The retirement of otherwise productive farmland is not without significant issues. However, it does appear to provide a reasonable solution to the District's long term drainage and water supply challenges from an economic perspective.

UPSTREAM WATER DIVERSION CONSTRUCTIONS ON TRANSBOUNDARY RIVERS

Miah M Adel[1]

ABSTRACT

The largest one among the ring of water diversion constructions that surrounds the Bangladesh delta is the Farakka Barrage on the Ganges. Meetings after meetings are held between India and Bangladesh without any permanent settlement of water sharing of any of the transboundary rivers. In case of the Farakka Barrage, what are achieved are occasional short-term water-sharing treaties with the succeeding one less favorable for Bangladesh than the preceding one because of the absence of arbitration and a guaranteed minimum flow at the Farakka point. Some of the other transboundary rivers with water diversion constructions are the Mahananda, the Tista, the Khukshi, the Talma, the Bhairab, the Kodla, the Madhumati, theJinjiran, the Korotoa, the Gomti, the Khowai, the Manu, the Dhali, the Pyan, the Punarbhaba, etc. Further, one dam is under construction at Tipaimukh on the headstream of the Meghna river that washes the northeast part of Bangladesh. Furthermore, India is working on a river networking plan for bringing water to south India's Cauvery river from the Brahmaputra that washes the northern part of Bangladesh. Water diversion constructions have led to severe flood seasons and hard-hit dry seasons for the downstream country. World nations should formulate international water rights laws and the UN should supervise fair sharing of water from international rivers.

INTRODUCTION

Out of 214 international rivers, about 148 rivers flow through two countries, 31 through three the countries, and the rest through four or more countries. The La Plata and the Elbe flow through five countries, the Chad, the Volta, and the Mekong through 6 countries, the Zambezi, the Amazon, and the Rhine, through seven countries, the Niger, the Nile, the Zaire through nine countries, and the Danube through twelve countries.

Instances of cooperative agreements on river flow sharing and river basin development exist among nations across the world. In 1954, six nations participated in the Mekong River Treaty based on fair distribution of water. Syria and Lebanon reached an agreement on sharing the water of the Orontes River. Mexico and the United States signed the treaty on sharing the Rio Grande and the Colorado river flows in 1944. France fulfilled Spain's demands (Sattar, 1996). In 1970, the settlement of the dispute over Vardar/Axois river between Macedonia (a

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republic of former Yugoslavia) and North Greece was done under the auspices and technical and financial assistance from the United Nations. It may be mentioned that the river basin area is 23,747 sq km of which 91% lies in Macedonia and 9% in Greek Macedonia (Goodman, 1997)

In south Asia, on the western sector India and Pakistan signed the Indus River Treaty to share six tributaries of the Indus. On the eastern sector, sharing water of thirty transboundary rivers including the Ganges, the Brahmaputra, the Teesta, and the Meghna, depends on India's mercy (Haque, 1997).

The article is meant to present the violation of water rights in course of constructing dams and barrages on transboundary rivers and reaching only temporary or no settlements at all under unilateral water withdrawals from transboundary rivers, and the grand plan of river networking as a further evidence of water rights violation in an even greater extent.

RING OF DAMS AND WATER-SHARING TREATIES

Bangladesh River Systems

The world's largest agricultural plain illustrated Figure 1 shows the location of Bangladesh and courses of the main transboundary rivers – the Ganges, the Brahmaputra, the Meghna, and the Teesta – along with their tributaries and distributaries. The agricultural plain includes 1.08×10^6 sq km, 0.577×10^6 sq km, and 0.091×10^6 sq km as the basin areas for the Ganges, the Brahmaputra, and the Meghna, respectively. The Ganges enters Bangladesh through northwest, the Tista from the north, the Brahmaputra from the north, and the Meghna from the northeast. The Ganges bifurcates into the Ganges (Padma) and the Bhagirathi (Hoogly) before entering Bangladesh – the former flows through Bangladesh to fall into the Bay of Bengal, and the latter through West Bengal of India to fall in the same bay. Calcutta Port is located at the mouth of the Bhagirathi.

Scenarios Leading to the Farakka Barrage

Following the setup of the Domodor Valley Corporation (DVC) in India, a number of dams were constructed on the tributaries of the Bhagirathi. These rivers lost their capacity to flash the Bhagirathi. India then constructed the Farakka Barrage 18 km upstream from the international border on the Ganges to divert the water flowing through Bangladesh to maintain navigability of the Calcutta Port located downstream about 260 km away (Figure 2). Crow et al.'s (1995) support that stagnation of the Port of Calcutta was more likely to

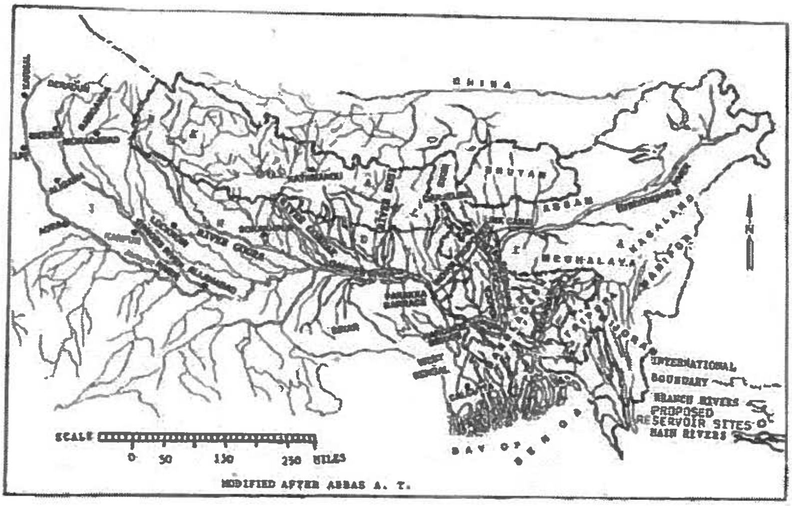


Figure 1. World's largest agricultural plain.

be explained by the decline of the industrial activity and overall economic activity than by the siltation of the Hoogly. Further, they add that a minimum research efforts or unfinished investigations for possible alternative to the construction of Farakka Barrage were performed. The port growth was one-fortieth of India's other port growth. It was at the acme of development during the British rule in India (1870-1947) when the port carried 40-50% of India's exports and imports. Afterwards, there had been a decline in the development of the port. The declination of the port growth had 23%, 11%, 10% in the mid-sixties, late seventies, and in the late eighties, respectively. India tried to blame the siltation of the Hoogly River for the relative economic decline of West Bengal. Dredging of the port was probably the best solution since the port failed to demonstrate convincingly the importance of the Farakka Barrage.

The Ganges Water Treaties

The Hardwar Barrage and the Farakka Barrage lie over the Ganges. Farakka Barrage was commissioned in 1975. Following a memorandum of understanding between India and Bangladesh, Bangladesh gave permission to withdraw water through the feeder can for 41 days — April 21 through May 31, 1975 — in the amount of 311.49 m^3/s, 339.80 m^3/s, 424.75 m^3/s, and 453.07 m^3/s during April 21-30, May 1-10, May 11-20, and May 21-30 respectively. But India continued unilateral water withdrawal beyond 41 days including the entire dry seasons (January through May) of 1975, 1976, and 1977 at the fullest capacity of 1,132

m^3/s of the feeder canal. Due to continued failure to come to a fair sharing treaty in meetings after meetings, Bangladesh raised the issue to the United Nations on September 20, 1976. Later, an agreement was signed on November 5, 1977, for a period of five years up to November, 1982. According to the treaty, out of the available 1,557 m^3/s discharge at Farakka, Bangladesh would receive 977 m^3/s and India the rest. If for some reason the flow at Farakka drops below 1,557 m^3/s, then Bangladesh will receive 80% of her share, that is 781.54 m^3/s. Bangladesh was subjected to heinous comments by the dailies published from Calcutta — the *Anandbazar* on August 28,29,1978; the *Satyakatha* on August 8, 1980; the *Zugantar* on January 12, 1981, etc. etc, — after signing the treaty.

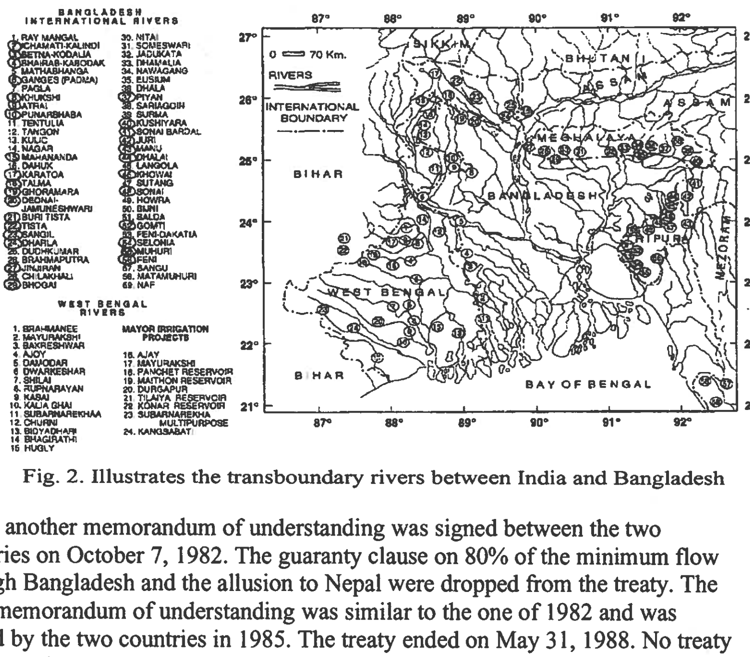


Fig. 2. Illustrates the transboundary rivers between India and Bangladesh

Later, another memorandum of understanding was signed between the two countries on October 7, 1982. The guaranty clause on 80% of the minimum flow through Bangladesh and the allusion to Nepal were dropped from the treaty. The third memorandum of understanding was similar to the one of 1982 and was signed by the two countries in 1985. The treaty ended on May 31, 1988. No treaty was operational during 1988-96 although the issue of the water diversion was raised to the UN 48th General Assembly in 1993.

India unilaterally withdrew the Ganges water during the dry season for those eight straight years. The current water sharing treaty was signed on December 12, 1996, for a period of 30 years. During March 1 through May 10, each country, in turn, will get 991 m^3/s flow lasting for 10 days. Even after signing the treaty, India was working against the treaty in the darkness, as she did in the past (Begum, 1988), of the night and blamed the solar radiation for not being strong enough to melt the Himalayan ice (Burns, 1997) The two treaties of 1977 and

1996 have been compared in Figs. 3a, 3b, 3c, and 3d. Whereas the average flow through the Bhagirathi is increasing for India (Figure 3a and 3b at top and bottom left), it is decreasing through the Bangladesh Ganges (Figure 3c and 3d at top and bottom right). The sources of the data are the Daily Dinkal (1996), the Daily Janakantha (1996), Hossain et al., (2003), Sattar (1998).

The treaty lacks a guaranty clause for the fair share of Bangladesh. If the discharge at the Farakka point drops below 1,500 m^3/s, the treaty will not work and the two countries have to meet an unknown number of times to come to a settlement and India will take that chance to divert water unilaterally as she did in the past. It is mentionable that 87 meetings – in experts level, secretarial level, ministerial level, Joint River Commission level, etc. etc. - were held up until December 12, 1996. It is thought, however, that no more treaty will be required when the current one ends because of unavailability of water at the Farakka point following increased withdrawals. The dam at Kanpur in Uttar Pradesh will be completed by that time.

Bangladesh has always pleaded for inclusion of Nepal in the meetings to settle the water disputes since the Ganges has tributaries originating from Nepal. India has never paid any attention to that. What has been observed is that India advocates for bilateral discussion but follows unilateral decision. However, a tripartite level meetings between India, Bangladesh, and Nepal can alone lead to the permanent settlement of the water disputes.

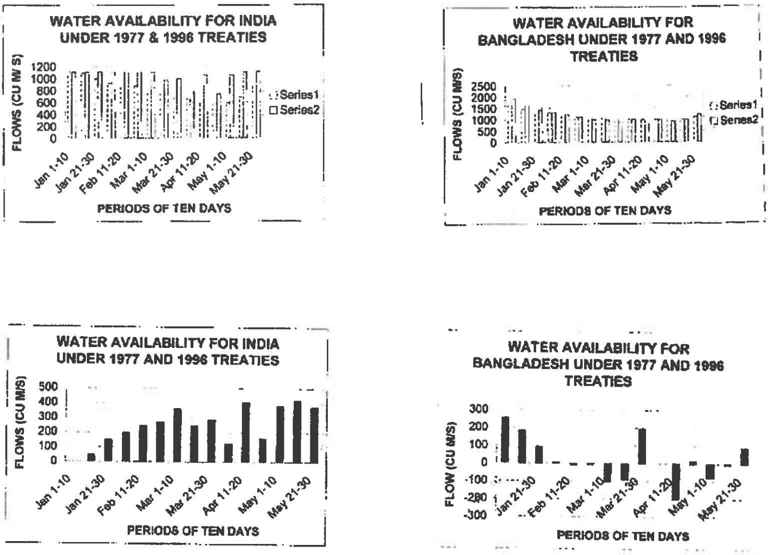
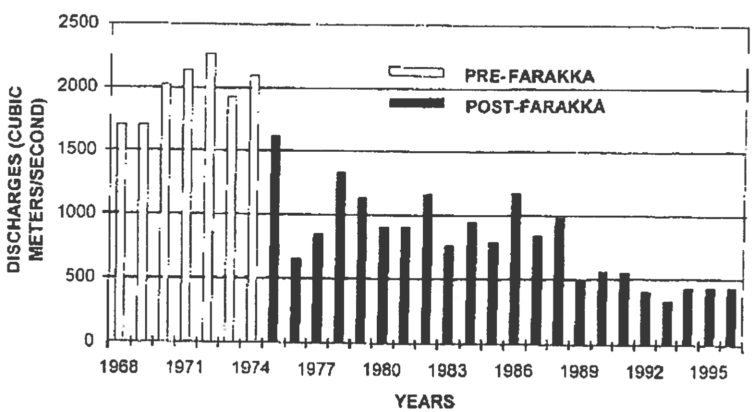


Fig. 3 and 3b in top and bottom left, and 3c and 3d in top and bottom right

During the dry season India withdraws nearly all the Ganges flow by the Hardwar Barrage built in 1854 (Hillary, 1997). Fig. 4a shows the dwindling Ganges flow, and Fig. 4b, the Ganges bed following the minimum flow.



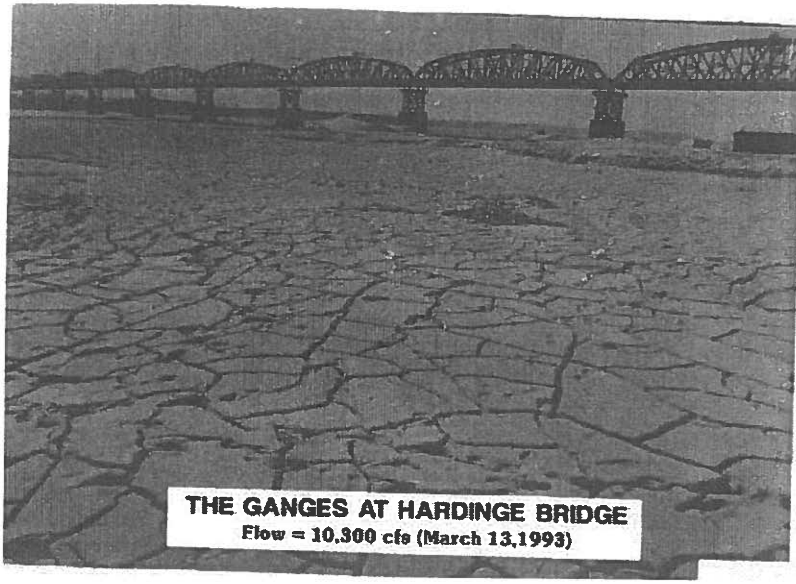


Figure 4b. Dry and fissured bed of the Ganges (courtesy of Shakoor Majid)

The Tista Barrage

India built the Tista Barrage at Gazaldoba in the district of Jalpaiguri with which she diverts 42.5 m^3/s of water from the Tista into the Mahananda in the dry season. In 1983, a memorandum of understanding reached between the two countries in which Bangladesh was to get 36%, India 39%, and 25% for reserve. However, no settlement has yet reached.

The Mahananda Dams

The Mahanda, the only tributary of the Ganges in Bangladesh., faces two dams – one at about 3 km and the other at 32 km upstream (at Khodaimaree) of Tentulia. A 42-km long canal from the dam site links the Tista and the Mahananda rivers. Dry season water diversion from the Mahananda affects the northern districts of Rangpur and Dinajpur in agriculture, industry, natural balance, people's livelihood, etc. etc.

Mini-Farakkas

The transboundary rivers that face dams and other water diversion constructions are the Ichamati-Kalindi, the Betna-Kodalia, the Bhairab-Kabodak, the Khukshi, the Atrai, the Korotoa, the Talma, the Ghoramara, the Deonai-Jamuneshwari, the

Buri Tista, the Sangil, the Dharla, the Jinjiram, the Bhogai, the Piyan, the Kushiyara, the Sonai Bardal, the Juri, the Manu, the Dhalai, the Khowai, the Sonai, the Gomti, the Selonia, the Muhuri, and the Feni. The location of these rivers are shown in Figure 2. Water diversion has affected agriculture, fisheries, and navigation in their basins.

PROJECTED DAMS AND RIVER NETWORKING

The Tipaimukh Dam

India is building a dam upon the Barak river in Assam, upstream of the Meghna to store $15.9x10^9$ cubic meter of water. This Tipaimukh dam is located 200 km upstream of Amalshit, the point where the Barak River splits into the Surma and the Kushiyara in the states of Manipur/Mizoram in India. The dam will be used to reduce the dry season flow in the Kushiyara and the Surma rivers, the headstreams of the Meghna river in north-east Bangladesh, increase siltation in them, and cause floods in the downstream.

River Networking

India is planning to divert 200 to 250 BCM of water from the Brahmaputra, the Tista and the Meghna basins through about 1,500-km link canals to the Cauvery River of south India. Figure5 illustrates the grand network of the plan (courtesy of Hossain et al, 2003, personal communication). The link canal will extend from Dhubri region of Assam to upstream of Gazal Doba on the Indian Tista of the Indian district of Jalpaiguri. Further, link canals will be dug from the Sankosh (a tributary of the Brahmaputra) and Manos rivers of Bhutan to add to the Brahmaputra-Tista canal. Later, a 473-km long link canal will connect with the Ganges upstream of the Farakka point. Because of mistrust upon India and the potential environmental problems, Bangladesh government earlier rejected the link canal proposal through Bangladesh (Figure 1). In the second phase of the grand networking of rivers, a link canal will connect the Ganges with the Cauvery of south India through many more small canals linked with the main canal. This artificial control of the river will make the Ganges dry. Also, the rivers – the Tista, the Torsa, the Raydhak, the Jaldhala, the Mahananda, etc. - that discharge water to the north-west Bangladesh will be controlled by India.

SOLUTION

Violation of water rights outweighs violation of human rights. World nations should convene to formulate laws for protection of international water right and world surface water resources. Since water world has a vital role in global warming, unilateral tampering of international rivers should be considered as important an issue as the reduction of the release of green house gases. Donor agencies that finance water diversion constructions should consider the downstream effects arising from their operations. Under the auspices of the UN, interests of all nations – big and small - should be considered in the sharing of transboundary water flows.

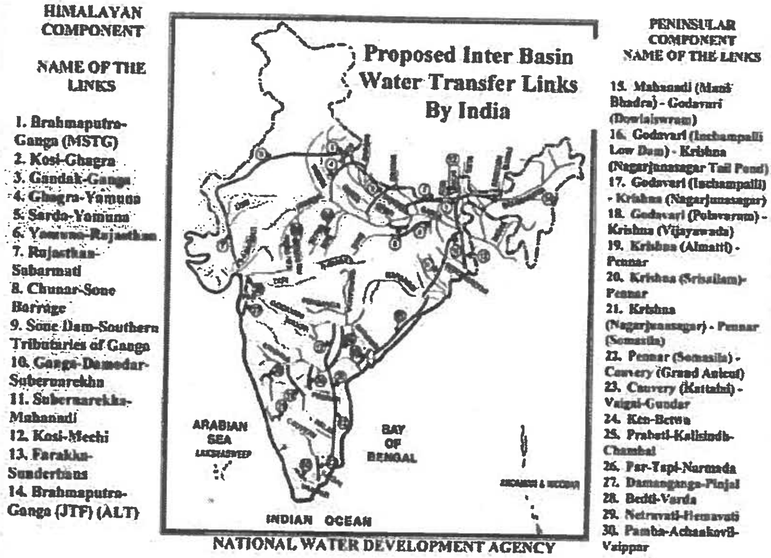


Figure 5. The grand river networking plan (courtesy of Hossain et al., 2003)

CONCLUSION

Diversion of water due for the downstream country by the upstream country is a gross violation of water rights. India buys time to develop further water diversion constructions in the procrastination of coming to a permanent settlement of the water disputes over all the transboundary rivers. At the end of the current Ganges water sharing treaty with India, no water will reach the Farakka point due to increased upstream withdrawal. The Ganges will be reduced to a large flood plain. The river networking plan will reduce the Brahmaputra, the Tista, and the Meghna to the same condition as the Ganges. For a permanent solution to the water disputes, India's willingness to include Nepal as the third party is necessary, and the UN should formulate the treaty. International laws are required to save the sweet water resources and the ecosystems in south Asia on an urgency basis.

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DYNAMIC REGULATION SOFTWARE MIGRATION TO JAVA

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ABSTRACT

The Société du Canal de Provence conceived, thirty years ago, the “Dynamic Regulation” software (Rogier 1987). This software has been used to control the Canal de Provence since that time. It has also been implemented on other systems in the world. The migration towards the Java language makes it independent of the operating system and has the advantages of an object-oriented programming approach that reinforces its evolutivity.

The article recalls first the basic principles of dynamic regulation. It reviews then the classes of objects that constitute the software. These classes correspond to

- Physical elements of the system (sections of canal, check structures, intakes and off takes)
- Functional elements that define the rule of operation and control logic.
- Utilities for data acquisition and user interfaces.

The review of the classes allows to describe the methods used in the software and to put forward the advantages of the object oriented approach, while taking advantage of computer developments achieved on previous projects. The computer modules can easily be adapted to the specificities of new projects: modeling new physical classes of objects, adaptation of functional classes of objects. It is thus possible to take into account particular constraints and objectives of each project. Indeed, these are intimately linked to the technical and social context.

The software has been developed to replace the version used currently on the Canal de Provence. It can also be integrated to other systems using SCADA. In addition it can also be used in simulation mode, with channel behavior simulated by a numerical model. Scenario results obtained using SIC (Simulation of

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Irrigation Canals) software developed by the Cemagref. (Sic 1992) will be shown during the Interactive Visual Presentations Session of the conference.

INTRODUCTION

JUThe Dynamic Regulation software works at the Société du Canal de Provence (SCP) since 1970. This software has been written in Fortran language and run on OpenVms system. Like any other on-field application, in the course of time or at the time of its implementation on other canal sites, this software has been adapted in order to face to new problems.

The Canal de Provence is completely automated and user oriented. Water users can take the water freely with resorting neither to rotations nor to any sort of priority allocation. Maximum flow and delivery pressure are fixed by contract. This mode of water supply leads to a very high water use efficiency (about 85 % between the volume charge to users and the volume taken from the reservoirs on the river).

A review of about 30 year's experience of automated canal management has been done and resulted in the decision to undertake a rewriting of the software. In our mind, a regulation software is the translation, in the field and in concrete actions, of the general strategy of canal management based on the geometrical, physical and functionalities of the whole system of regulation.

Concerning the language, it appears that an object oriented one would be the most adapted, likely to represent very well hierarchised and articulated actions or components of the system. Moreover, what is needed for the development is:

- An improvement of the software documentation, with an automatic update in case of modification of the sources.
- A great potential evolving with an increased modularity, so as to accept easily modifications and adaptation to a particular canal site.
- An independence of the target computer.

The chosen language has been Java. This choice allows also a graphical specification method: UML (Booch 1999) by means of Rose software.

We have then proceeded as follow. The Canal de Provence has been numerically modeled with Sic (SIC 1992), the software of Cemagref which can simulate canals behavior with all operational structures, off takes and perturbations. In this first step, the application we have to develop behaves like an on-field application, the numerical model playing the role of the canal. Exchanges take place by means of files, just like the field application: receiving measures from the transducers on the canal, sending actions to be performed on control structures. The final purpose being to be able to replace the canal model by the canal itself, without changing anything, once the tuning of the regulation is done.

The next section recalls the principles of the Dynamic Regulation strategy. Section 3 describes classes of objects connected to the topology part of the application. Section 4 presents the process of the Dynamic Regulation in term of classes of objects and method related to them.

THE DYNAMIC REGULATION

A high level of efficiency in water transportation and distribution is achieved thanks to a good organization and a supervisory and water control system which supplies the right amount of water, at the right time, and at the right location.

Among the elements of such a system the "Dynamic Regulation" control software.(Rogier 1987) automatically controls main canal and control structures. The control software performs simultaneously three different actions:

- Anticipatory action (demand forecasting and open loop control) :
  Depending on the type of off take, flow forecasting can be generated either from a pre-established program, or by extrapolation of historical trends. This second method combines the discharge measured at the off take and a running average computed over the preceding ten days.

  The forecasted discharges at check structures are then calculated by introducing a hydraulic delay from the check structure to the various off takes. Target volumes of the different pools are calculated from these forecasted discharges taking into account operating constraints (minimum and maximum water level). Between these two limits, the choice of the target volumes may follow different objectives, such as to minimize the response time of the canal or to optimize the energy cost/benefit at pumping stations or turbines.

- Corrective action (feedback):
  Pool inflow and outflow cannot be perfectly balanced in practice. This results in volume variations in each pool which have to be counterbalanced by a *corrective action.* This corrective action is computed through a local controller (PI controller, pole placement controller, smith predictor or any other type of controller).

- Coordination action:
  The corrective action can be different for two adjacent pools and introduces a discrepancy between inflow and outflow in a pool. Thus, it is recommended to mitigate this imbalance by carrying forward the corrective action from one pool to the other upstream pools. However, this action, called co-ordination action, is not mandatory as any imbalance can be corrected by another corrective action. Coordination actions speed up the control process and help maintain the pool volume closer to their targets.

SOFTWARE ORGANIZATION

An object oriented software is organized into several classes of objects, each class defining on one hand data or "members" required to describe the object and on the other hand the collection of "methods" which can be used to carry out treatments.

The renewed "Dynamic Regulation" is composed of more than 100 classes which can be spread into 3 main packages:

- Topology package related to physical elements of the system
- Regulation package related to functional elements that define the operation rules and control logic of the system
- Utilities package for data acquisition and user interface.

We are not going to detail all classes of the application, let us simply choose some classes and describe their main characteristics and implemented functions.

The most general class of the software is called *"CXMLObject"*, all other classes inherit from this one. It implements several functions as the building of an object through the reading of parameters in a file of XML format. In addition to inheriting behavior from *"CXMLObject"* specialized classes include new specific functions or data.

Topological package

The Topology is the first notion to be structured. All classes of this package inherit from the *"CTopologicObject"* class which adds to the *"CXMLObject"* the possibility of connection to sensors for physical measurement of object status. Below this package most general class, we find:

> *"Conduct"* which inherits from *"CTopologicObject"* and add the possibility of connection to other *"Conducts"* located upstream or downstream. A "Conduct" is able to propagate its real discharge from upstream to downstream and its forecasted discharge from downstream to upstream.
>
> *"Segment"* which is a specialized *"Conduct"* dedicated to represent the basic geometrical canal element. It represents a linear section of canal. This class adds the possibility of calculation of volume of water in the canal and possesses eventually *"Off/In Takes"* modeled through a new class family.
>
> *"ControlStructure"* is a specialized *"Conduct"* which represents a structure on the canal through which the system is able to measure and adjust the discharge. It can be divided into several *"Passes"* as *"Gates"* or

"Pumps", if we need a more detailed description of the *"ControlStructure"*.

A *"CRamification"* is required if a *"Conduct"* is connected to more than one other *"Conduct"* upstream or downstream.

Regulation package

The basic class of this package is the *"HydraulicUnit"* which is a specialized *"CXMLObject"* made up of *"Segments"* and limited upstream and downstream by *"ControlStructures"*. The *"HydraulicUnit"* controls the status of its segments through action on upstream *"ControlStructures"*. This class includes functions required to implement operational rules and control logic. Two different *"HydraulicUnit"* have been developed:

- The *"ControlledVolumeHydraulicUnit"* is able to maintain the volume of water in the canal close to a target volume which depends on canal discharge.
- The *"PumpingStationOptimizationHydraulicUnit"* manages the stored volume so as to reduce pumping costs (minimizes pumping duration during day time and maximizes it during night time)

"HydraulicAdductions" are composed of several synchronized *"HydraulicUnits"*. This class gives the opportunity to share deficits or excess among several *"HydraulicUnits"* or to implement a full MIMO controller (Multiple Input Multiple Output controller).

The main basic classes presented here above are illustrated in Figure 1.

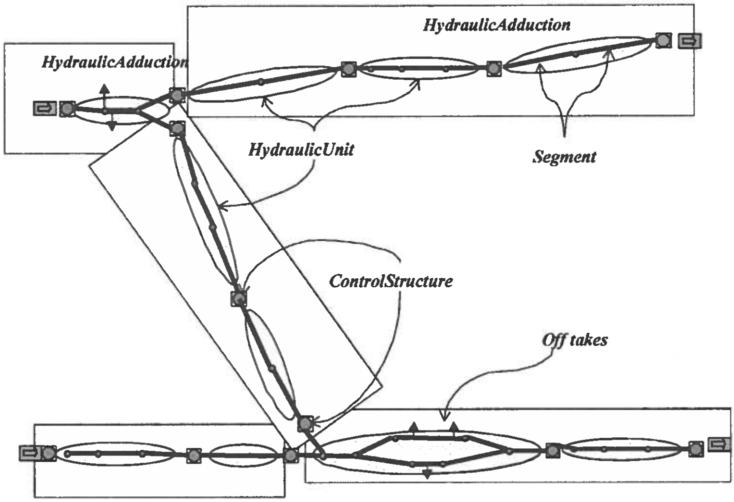

Figure 1. Topological graph of a canal system

Figure 2 gives the synopsis of the hydraulic unit class.

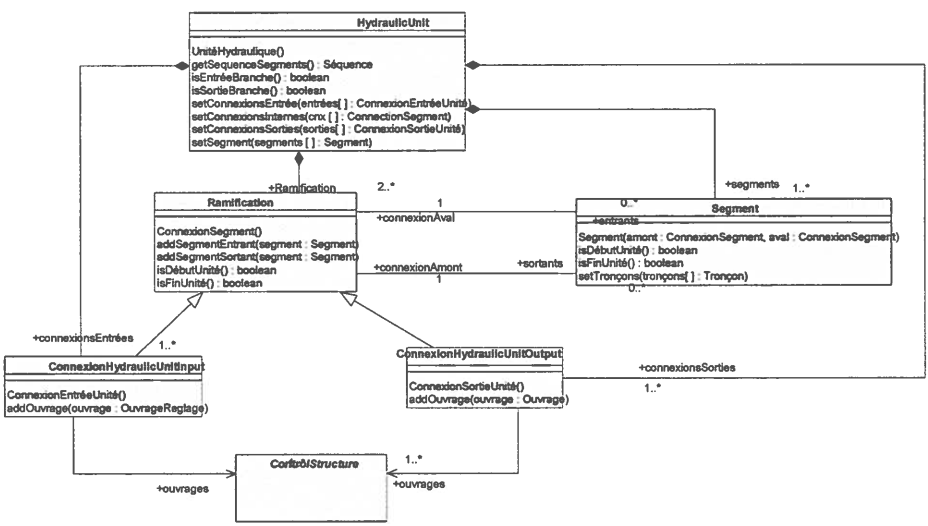

Figure 2. The hydraulic unit object

Utilities package

The utilities package consist of

- Classes devoted to data acquisition as *"CommunicationLink"* through which the software can be connected to supervisory software. One *"CommunicationLink"* manages several *"Sensors"* or *"Commands"* which are able to get/send information from/to field equipment.
- Classes devoted to user interface as *"DataLogging"* to memorize all events and actions performed by the software or *"ControlReport"* which creates at each control time step one report presenting system status and commands sent to the field. This last element present for example target and measured volume and indicates if some degraded procedure has been used in case of failure of any field equipment.

THE REGULATION PROCESS

Initialization

The purpose of the initialization phase is the building of the system to control starting from a configuration file which defines the topology and the physical characteristics of the various components.
This file is of XML format, and it is the role of a class "building" to read the file and to construct the system.

Calculation of previsions

The hydraulic adductions being independent for the Dynamic Regulation process, the prevision process is realized independently for each of them.
The principle of the prevision process consists in starting from the previsions attached at the off takes (which are at the segment level) and to propagate them from downstream to upstream taking into account the physical characteristics of the crossed sections, like time delays.
Specialized classes, hierarchised from segment to adduction passing through unit levels, are devoted to the calculation and gathering of prevision scenarios.

Correction part of the regulation

The corrective part of the regulation process lies in the comparison between set points and measurements performed by the sensors.
For each hydraulic unit the process is the following:

- Calculation of the volume of the hydraulic unit.
- Calculation of the deviation between this volume and the set point.
- Calculation of the corrective discharge.

These treatments follow the class structure shown in figure 3.

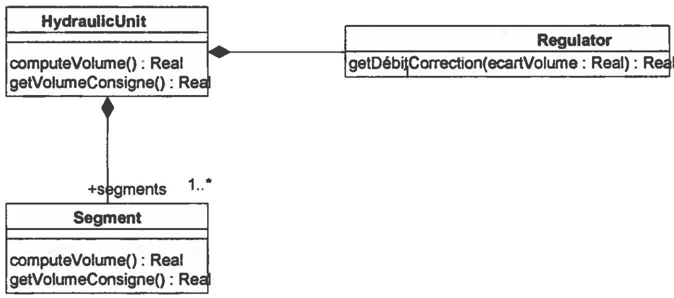

Figure 3. The class structure of the corrective part of the Dynamic Regulation

The calculation of the corrective discharge is devoted to a utility class "Regulator", which implements the needed algorithms. Like in the prevision process, the segment classes and their methods performed the main part of the calculations.

Coordination part of the regulation process

The last component of the Dynamic Regulation concerns the coordination between the downstream and upstream control structures of a hydraulic unit. It aims at taking into account, for a given hydraulic unit, the various corrections on its downstream structures and to carry them on its upstream structures, following the graph shown figure 4.

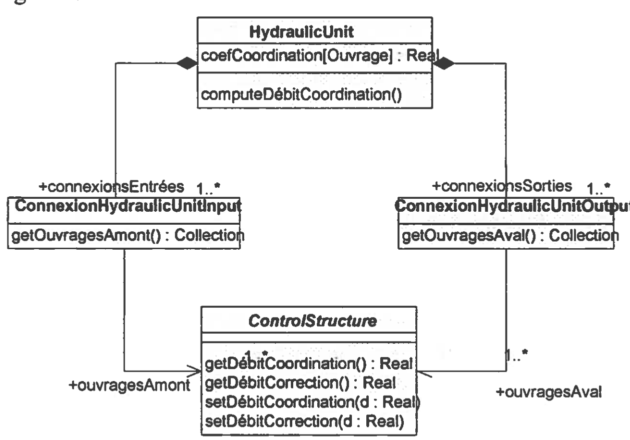

Figure 4.Class structure of the coordination part

Communication shell

The transmission of set points to the control structures and the recovering of measurements of the various sensors need a communication shell. The development of the communication shell does not strictly belong to the field of the Dynamic Regulation, which must be interfaced with an existing communication system. The communication protocol with this communication system uses exchange of files, along the functional graph figure 5.

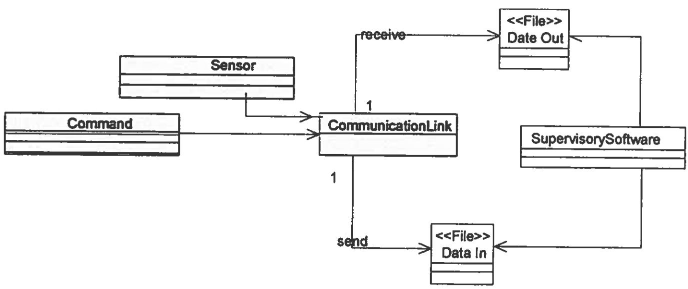

Figure 5. Communication interface

Any particular equipment delegates to a class "device" the exchange of data with the canal system.

CONCLUSION

We have described the logic of the application. One can easily notice that the general structure is more rational and easy to maintain and adapt to particular canal sites. One can also notice that the controller itself is a well isolated and small part of the whole software. It can be changed, and, for the same canal, it can be different from one hydraulic unit to another. At the present time, a library of controllers exist which includes PI,PID, Pole Placement three order controller, Smith Predictors, Internal Model approach.

At the present time, the application, developed along these features, is implemented on computer driving the Canal de Provence modeled with Sic. The regulation runs in the same way as in the on-field application. We have begun a series of test scenarios and also we reproduce, in parallel, real cases for certain points of the Canal domain. It is then expected, in the plan of work, to perform the migration of the Canal de Provence regulation at the end of 2004.

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EPDM RUBBER LINING SYSTEM CHOSEN TO SAVE VALUABLE IRRIGATION WATER

Ronald K. Frobel[1]

ABSTRACT

The distribution of valuable irrigation water using some type of conveyance such as a canal has been in use for thousands of years. Due to excessive seepage loss, many types of lining systems have been used since early times including soil liners, paving bricks, bitumen and clay. With the development of polymers and the expansion of the plastics industry in the 1940's, 1950's and 1960's, sheet materials such as Polyethylene, Polyvinyl Chloride (PVC-soft), Butyl and EPDM Rubber became popular in agricultural applications (Comer et.al, 1999). With the rapid development of the geomembrane industry in the 1970's and 1980's polymeric sheet materials were developed specifically for many civil applications including the waterproofing of distribution canals. EPDM rubber sheeting has proven to be one of the most durable and cost effective exposed synthetic lining system for use in canal rehabilitation.

As a successful example of recent installations, the Tulelake Irrigation District (TID) located in Northern California installed over 4 miles of EPDM rubber lining under the guidance of the U.S. Bureau of Reclamation. Historically, the TID has faced loss of deliverable water due to high seepage rates in unlined canals and laterals, approaching 50 percent in some cases. This, in addition to the drought conditions here and in other western and southwestern irrigation districts, has prompted the federal government to initiate a program for the selection and installation of low cost, low tech synthetic canal lining systems.

This paper will focus on the selection, cost, installation methods and effectiveness of EPDM rubber canal lining systems as used in the TID emergency seepage control program. In addition, a Texas case history will illustrate the use of EPDM rubber for the repair of old, deteriorated concrete lined canals.

INTRODUCTION

One of the major early uses for flexible membrane liners or geomembranes has been in the waterproofing of canals and laterals used in water distribution for agricultural irrigation and their use has been documented as early as the late 1930's in the western U.S. Early lining systems included bitumen coated burlap and

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eventually thermoset elastomeric liners such as Butyl Rubber (IR) and Ethylene Propylene Diene Monomer (EPDM) which were also being used in the lining of canals and water containment reservoirs (Comer, et.al, 1999). In fact, according to Staff (1984), rubber linings were even used prior to the 1930's for the containment of water and Polyvinyl Chloride (PVC-soft) was used in the 1940's in buried applications. Thus, the use of synthetic polymers for canal lining is nothing new and has been a viable alternative to much costlier concrete.

Earth Lined Canal Rehabilitation – Tulelake Irrigation District (TID), California

The Tulelake Irrigation District (TID) supplies valuable agricultural water to the over 25,500 hectares (63,000 acres) of otherwise dry but fertile lands of the northern California counties of Siskiyou and Modoc as well as Klamath County, Oregon. It is one of 18 districts in the U.S. Bureau of Reclamation Klamath Project which is one of the oldest irrigation projects in the Western United States. Irrigation water has always flowed to the approximately 800 farms using a vast network of over 390 km (242 miles) of main canals, laterals and ditches, some of which date back to the turn of the century.

Historically, the irrigation district has faced loss of deliverable water due to high seepage rates in unlined canals and laterals, approaching over 30 and sometimes as high as 50 percent. This, in addition to the drought conditions here and in other western irrigation districts, prompted the federal government to intitiate a program for the selection and installation of low cost, low tech lining systems that can be 100 percent installed and maintained by the irrigation district personnel without the need for specialized installers or contractors. Materials must be capable of being installed in harsh, rough soils conditions, resist animal traffic and be left exposed in excess of 20 years.

The M-2 Lateral

In June of 2001, the U.S. Bureau of Reclamation, Mid Pacific Region, issued a Request for Proposals (RFP) to supply a synthetic lining system to line the M-2 lateral of the Tulelake Irrigation District from sta 0 + 00 to sta 121 + 92 or approximately 3.7 km (2.3 miles). The request specified an exposed geomembrane system that could be installed, seamed, repaired and maintained by irrigation district personnel. The maximum panel size was limited to 9.14 m x 61 m (30 ft x 200 ft) with a minimum thickness of 1.14 mm (45 mils). The geotextile required for extreme rocky outcroppings was a minimum 340 gm/sq m (10 oz/sq yd) nonwoven protection fabric. The government required that a review panel select the geomembrane system based on the following evaluation criteria:

1. Technical Capability
    a. Ease of Installation (Delivery, Placement, Seaming by TID)
    b. Damage Resistance (During Placement and Operation)
    c. Ease of Repair (Repair by TID over life of the lining)
    d. Expected Life (Manufacturer 20 year warranty for exposed conditions)
    e. Seepage control (Effective barrier material)
    f. Descriptive Literature addressing the above
2. Past History and Performance
3. Price

The final selection of a supplier was based primarily on technical merit, the opportunity for installation by TID personnel using their own equipment and characteristics of the geomembrane material as well as low cost. Thus, the lowest bid price was not the principal determining factor in the final selection of the system.

The canal section to be lined was a canal that was originally earth-lined and built in 1942. It has some rocky reaches and known high seepage loss in excess of 30 percent. Technical characteristics included the following:

$Q = 2$ cms (72 cfs)
$V = 0.4$ m/s (1.32 fps)
$D = 1.22$ m (4.0 ft)
$S = .00015$

Side slopes were an average of 1.5H : 1V and base width varied between 1.8 m and 2.4 m (6 - 8 ft). Total width of the section including flat runout anchors at top of slope was 9.14 m (30 ft). Thus, geomembrane panels delivered to the site were required to have a 9.14 m (30 ft) width with no longitudinal seams. Seaming in the field was to be at panel ends only and across the width of the canal section.

EPDM Chosen for Superior Technical Characteristics and Low Cost

The U.S. Bureau of Reclamation, Mid Pacific Region awarded the project to a material supplier of 1.14 mm (45 mil) thick Ethylene-Propylene-Diene-Monomer (EPDM) rubber geomembrane based on the above technical evaluation factors and low cost. EPDM geomembranes have been in use worldwide for over 40 years in a wide variety of containment applications including large and small irrigation canals. EPDM was chosen for the Ochoco and Talent Irrigation Districts in Oregon to line canal sections with extreme water seepage. Both of these projects utilized the irrigation district crews for soils preparation, EPDM installation, seaming and connections to structures.

EPDM Geomembrane Placement by the Tulelake Irrigation District

EPDM factory panels were manufactured in custom sizes for the TID M-2 Lateral. Each panel was 9.14 m (30 ft.) in width by 61 m (200 ft.) in length, folded along the length and then rolled for delivery and handling on site. Once the rolls of panels were delivered to the site, the TID deployed the panels using their own equipment and a crew of eight workers. District personnel fabricated a custom lifting bar which was suspended by cable from the bucket of an XL4100 Gradall. The rolls of EPDM were lifted from a flatbed truck, positioned in the channel bottom and unrolled along the channel by advancing the XL4100 Gradall along the channel access road.

Once the panels were unrolled and unfolded up the side slopes, they were positioned and placed into the anchor benches on both sides of the channel section. The ends of the panels were then overlapped a minimum of 150 mm (6 in.) and the overlap area was cleaned and primed. The overlap area was then tacked without wrinkles and an adhesive tape seam system was applied by the TID crew. The field-fabricated seams were composed of prefabricated 150 mm (6 in.) wide rolls of partially vulcanized cover strips with adhesive backing. Once the strip was placed and centered on the overlap, it was pressed down onto the two adjacent panels with constant hand roller pressure to ensure complete adhesion. Advantages of using the patented tape seam system include:

- Designed for remote areas and can be installed in cold temperatures
- No specialized welding equipment, hot air guns or supporting electric generator equipment is required
- Components are simple and can be stored at irrigation district shops for future use
- Seaming requires no specialized training (TID crew received 15 minutes of instruction)
- Resultant seam is a continuous 75 mm (3 in.) bond to panel edge with high peel and shear strength. Seam area will resist movement under load of over 300 percent without affecting the waterproof integrity
- The same seam methods are used for repair patches by TID maintenance crews.

During the placement of panels, it was noted that the EPDM sheet material was not susceptible to wind uplift even by high winds which are a frequent occurrence at this site. The EPDM rubber sheet conforms readily to the subgrade, lays flat and adheres to the soil due to surface friction, unit weight and flexibility (intimate subgrade contact and conformance).

Once the panels were in place and seamed, the TID crew placed soil cover on the anchor benches and compacted the material at top of slope with dozer or motor grader wheel loading. It was noted that during soil placement and grading on the top of the channel that some large angular rocks in excess of 34 kg (75 lbs) were displaced and rolled down the EPDM slopes. No puncture damage or marks were noted on the EPDM due to rock fall. Although there is no requirement for soil cover on the bottom of the channel, sediment, upper slope soils and wind blown soils will accumulate over time providing a deposited soil cover.

Concrete Lined Canal Rehabilitation - Harlingen Irrigation District (HID), Texas

The Harlingen Irrigation District (HID) No. 1 is located within the boundaries of Cameron County, the southernmost county in Texas. The District extends approximately 32 km (20 miles) north from the Rio Grande River and approximately 13 km (8 miles) north of Harlingen, Texas and maintains 3309 irrigation accounts. The District obtains water from the Rio Grande as authorized through the Texas Commission of Environmental Quality (TCEQ) which includes 98,232 acre-feet of irrigation water as well as municipal water. The District has 64.3 km (40 miles) of earth lined canals constructed between 1905 and 1915, 41.8 km (26 miles) of concrete lined canals constructed in the 1950's and 1960's and 250 km (155 miles) of pipelines extending from the canal systems. Approximately 25% of the water diverted from the Rio Grande is lost to seepage. The District intends to conserve water by lining the larger capacity canals with geomembrane liners and converting some of the smaller canals to pipelines with funding coming from a variety of State sources as well as the North American Development (NAD) Bank, Water Conservation Investment funds.

The Wyrick Canal

The HID project improvements include the rehabilitation of 15 km (9 miles) of existing concrete lined canals that have been severely damaged due to excessive ground movement. Repair will be implemented by placing an exposed geomembrane lining system directly on the damaged concrete sections, thus eliminating the need for removal. Lining will be limited to the large capacity canals with flows greater than 2.3 to 4.0 cms (80 to 140 cfs).

In July, 2003 the HID purchased 1.14 mm (45 mil) thick EPDM rubber for the exposed geomembrane system to be placed on the Wyrick canal. The Wyrick canal's original concrete lining was cracked throughout and excessive seepage in excess of 20% was noted. The canal section is trapezoidal in shape with 1.5:1 side slopes and base width varying between 1.8 and 2.4 m (6 and 8 ft) and total prism width averaging 5.0 m (16.4 ft).

The HID selected EPDM rubber as the geomembrane system based on the following evaluation criteria:

1. Technical Evaluation
   a. Installation (Placement, Seaming, Maintenance by HID)
   b. Resistance to Damage (Placement and Operation)
   c. Repair by the HID over the Life of the Lining
   d. Life Expectancy (20 year minimum)
   e. Effective and Proven Seepage Control
   f. No Requirement for Geotextile Underlayment
   g. Flat Surface Installation (no wrinkles)
2. Texas Valley Prior History and Performance
3. Low Installed Price and Low Maintenance Costs

The EPDM geomembrane panels delivered to the site were custom sized 6.10 m (20 ft) in width and 30.5 m (100 ft) in length. The panels were folded along their length and then rolled on a core for delivery and handling on site. As with the TID, the HID personnel placed and field seamed all panels using their own equipment. Anchoring at the top of slope was provided by a 450 mm (18 in.) deep "V" trench cut in close to the top edge of the concrete and later backfilled with the excavated soil. The upstream and downstream ends of the EPDM lined section were anchored into the concrete section by placement into a 300 mm (12 in.) wide groove cut 450 mm (18 in.) deep across the entire width of the concrete section. The ends of the panels were placed into the groove and then the groove was backfilled and flush finished with concrete thus forming the transition from concrete to rubber lining.

Once the rolls were delivered to the site, the HID deployed the panels using their own equipment and a crew of 6 workers. District personnel pre-fabricated a metal lifting bar that passed through the core of each roll for lifting from a flatbed transport truck. Each roll was lifted by a large backhoe from the truck, positioned across the channel bottom and then unrolled down the channel by advancing the backhoe along the channel access road. After unrolling, the panels were unfolded and pulled up the side slopes, positioned flat with no wrinkles and placed into the "V" shaped anchor trenches. Overlap seaming was accomplished by district personnel using the same techniques described in the TID installation. Final installation was smooth and wrinkle free due to the conformability, unit weight and flexible properties of synthetic rubber membranes.

SUMMARY

The TID and the HID successively installed an exposed EPDM geomembrane system using custom manufactured panels, district personnel for installation and seaming and district equipment for the soils preparation and backfilling. The combination of low cost and user friendly materials that can be installed by irrigation district personnel with minimal training and no specialized equipment is an outstanding alternative to other systems and an excellent method for old canal lining rehabilitation.

EPDM rubber geomembranes are an outstanding alternative for use in the rehabilitation of old canals and laterals of western irrigation districts for the following reasons:

- Minimal preparation of the channel section or concrete surface using district equipment and personnel.
- User-friendly ease of panel installation with district equipment and personnel.
- User-friendly low tech seaming and repair methods by district personnel.
- Mechanical properties to resist installation and operation stress in an exposed environment (puncture/impact resistance, working strain to over 500 percent)
- Attachment to concrete and steel structures (gates, turnouts, pipes, etc.) using special waterproof adhesive systems, conventional batten bar attachment or simplified ballast attachment.
- Lay flat (soil friction and unit weight) characteristics to resist wind uplift/displacement.
- Lay flat wrinkle free installation over concrete.
- High UV / weathering resistance backed by decades of exposed installations including installations in the desert areas of the southwest.
- Repair and maintenance by irrigation district using simple low-tech seaming techniques and repair kits.
- Custom panel sizes for differing channel sections.
- Installation and seaming in cold winter weather conditions (usually off-season October to March in northern climates).
- Resistant to animal traffic including deer and elk in remote areas.

The TID and the HID are typical of many irrigation districts in the western United States where conveyance channels are unlined or deteriorated with many losing between 30 and 50 percent of the deliverable water to seepage during the irrigation season. With water costs increasing and available water in short supply (especially during dry years or federally mandated allocation restrictions), irrigation canals and laterals are being evaluated for lining rehabilitation with exposed geomembrane systems. There are over 10,000 km (16,100 miles) of main canals and over 16,760 km (27,000 miles) of laterals in the western United States alone (Comer, et.al, 1999). Of these, only approximately 15 percent are lined. Although all reaches of canals or laterals do not need lining, the potential of those that will need lining or rehabilitation to save valuable irrigation water in the very near future is indeed large.

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A USER-CENTERED APPROACH TO DEVELOPING DECISION SUPPORT SYSTEMS FOR ESTIMATING PUMPING AND AUGMENTATION NEEDS IN COLORADO'S SOUTH PLATTE BASIN

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ABSTRACT

Throughout the United States, new models for computing augmentation requirements are being developed and applied. For the past eight years, I, along with my research team, the Integrated Decision Support Group (IDS), have had the opportunity to study the data and modeling needs of water users in the Lower South Platte River region in Colorado. With the active participation of the water users, IDS has prioritized the needs and then collected or generated the data and modeling tools necessary to meet these needs. This approach to Decision Support System (DSS) development is based on the premise that the user has a good understanding of what their current and future needs are, and with this in mind, we have developed an interactive and dynamic development process in which the users play an integral part. I refer to this approach as a "user-centered approach". With this approach, we have developed several data driven tools that are widely used in the South Platte Basin and other parts of Colorado. These tools are collectively called the "South Platte Mapping and Analysis Program" (SPMAP) (www.ids.colostate.edu/projects/splatte). The project has been funded by water users, the Colorado Water Resources Research Institute, Colorado Cooperative Extension, Colorado Agricultural Experiment Station, the Division 1 Office of the Colorado State Engineer, and the United States Bureau of Reclamation.

INTRODUCTION

In Colorado there is increased scrutiny of the amount of groundwater depletions caused by well pumping in alluvial aquifers. The impact of these depletions on river flows has prompted renewed interest in the methods used to calculate them.

Prolonged, severe drought and rapidly growing urban populations have exacerbated conflicts between ground and surface water users. Water managers are attempting to reconcile the desire to make use of the large amount of storage in the alluvial aquifer with the need to protect Colorado's Doctrine of Prior Appropriation and more senior surface water rights. In order to manage conjunctive use of surface and groundwater there are four components that need to be evaluated: 1) water demands, 2) water supplies, 3) depletions of groundwater, and 4) impacts to rivers due to depletions of groundwater and

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resulting augmentation requirements. SPMAP tools have been developed to deal with each one of these components.

QUANTIFYING WATER DEMANDS

In many instances, groundwater in the South Platte Basin in Colorado is used as a supplemental water supply: groundwater is pumped when surface water supplies are unable to meet demand. Therefore, the first step in modeling a groundwater/surface water system is calculating the water demand for the system. In agricultural systems, the demand is normally determined using either crop evapotranspiration (ET) or an estimate derived from multiplying well pumping by a factor (normally referred to as a Presumptive Depletion Factor - PDF). In order to quantify consumptive use, the IDS Group developed a consumptive use model called IDSCU for the SPMAP project. The IDSCU Model allows users to determine crop consumptive use, irrigation water requirements, and depletions of groundwater using both ET and PDF methods. The model also allows users to compare the estimates of groundwater depletions calculated by both methods.

In the past when crop evapotranspiration was used as the method to estimate groundwater depletions these demands were computed using monthly evapotranspiration (ET) equations with the most commonly used method in Colorado being the SCS Blaney Criddle method. However, since more complete weather stations were installed around the state in the 1990's, data has become available for using daily reference crop ET methods such as the Penman-Monteith or the new ASCE standardized reference evapotranspiration equation, and these daily methods are gaining in popularity. The IDSCU model allows users to compute ET using both monthly and/or daily methods as well as compare the results obtained by using different ET methods.

The model enables water managers to estimate the consumptive use (CU) of groundwater based on surface water supplies and crop consumptive use estimates. Surface water supply information and information collected by local weather stations can be imported from the Colorado State Engineer's Office database, HydroBase, or manually entered by the user. Weather station information can also be imported from the Northern Colorado Water Conservancy District weather stations, the Colorado Agricultural Meteorological Network (Coagmet), or manually entered by the user. The IDSCU Model can compute monthly CU using the SCS Blaney Criddle, Calibrated Blaney-Criddle, Hargreaves, and Pochop methods. Daily CU estimates can be computed by the model using the Penman-Monteith, Kimberly-Penman, and the new ASCE standardized reference evapotranspiration equation. The IDSCU Model Graphical User Interface (GUI) main window is shown in Figure 1. On the lower right hand side of the main screen a number of buttons are displayed which allow the user to access pop-up screens for entering or modifying data pertaining to: crop characteristics, crop coefficients, weather data, surface water supplies, modeling area information, well information, and weather station weights.

The IDSCU Model allows users to generate data to run the model before (pre) or after (post) the historical data period. The user may select to generate pre- or post-historical data by averaging selected years, repeating a selected year, or repeating a sequence of years (Figure 2) and computing the CU for them. The model is also capable of generating input and output displays for all year types (calendar, irrigation, and water).

The model can calculate CU or Irrigation Water Requirements (IWR) with or without using soil moisture. The model does a water budget and determines the times when crops might be water short as well as the amount of CU met from both surface and groundwater. As mentioned previously, with the IDSCU Model, users are able to compute the CU for multiple ET methods (both monthly and daily – assuming the data is available for both). The GUI allows users to compare the CU computed with different methods and computes ratios between the different methods. This functionality allows users to evaluate the difference between different ET methods as well as provide some guidance for users if they are interested in calibrating a monthly method based on the differences between the monthly aggregated values of daily ET methods and computed monthly ET values.

When pumping records are available, users may enter either monthly or total annual pumping. If the user enters total annual pumping the model has the capability of distributing the pumping into monthly values for agricultural or non-agricultural wells. The model also allows the user to enter a Presumptive Depletion Factor (PDF) for each well. The PDF is a calculated factor that estimates the amount of pumping that is used to meet CU. If the user provides values for pumping and a PDF, the model can calculate the depletions of groundwater to meet crop CU as pumping multiplied by PDF. The model also calculates the amount of groundwater depletion based on ET method(s) and a water budget. The model allows users to compare the depletions of groundwater based on both methods (PDF and ET) and check if the two values of depletion of groundwater are similar.

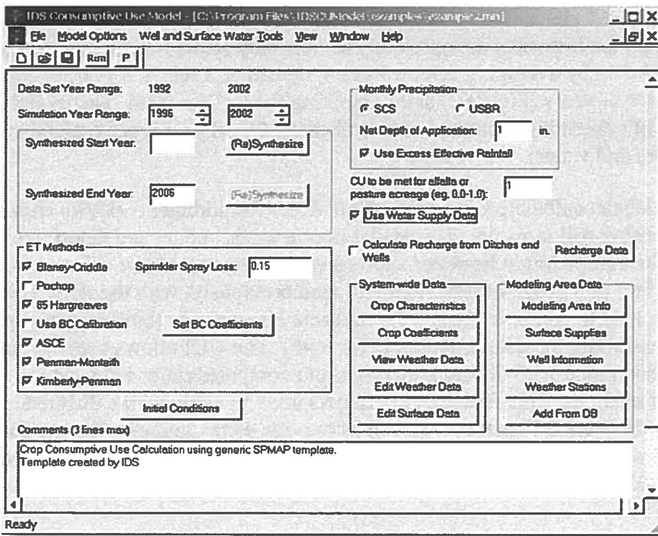

Figure 1: IDSCU Main Interface Window.

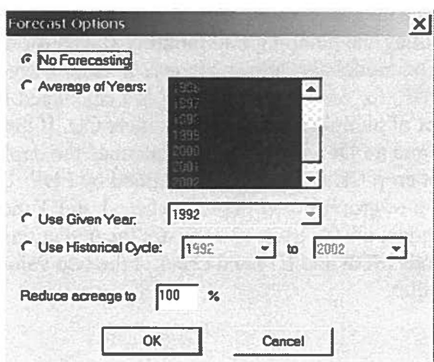

Figure 2: IDSCU Forecasting Options.

The computation of potential ET for all the methods includes an option for calculating a soil moisture budget. For the monthly models, surface water supplies can be specified to meet crop CU. If there is additional CU beyond what surface water supplies can meet, wells tied to a modeling unit are typically assumed to supply the additional CU. Weights can be assigned to weather stations, reflecting their relative influence in computing the CU for a particular modeling area.

QUANTIFICATION OF WATER SUPPLIES

Water supplies are normally from two sources 1) surface water supplies, and 2) groundwater pumping. The model allows users to query the State Engineers Office database (Hydrobase) in order to generate a set of diversion records for different ditches or diversion structures. Users may also build a set of diversion records for different ditches or diversion structures by entering the diversion records manually. The surface supply for each modeling area is then calculated by assigning one or more surface supply ditches or structures to it. The IDSCU Model requires users to enter the shares for each ditch or structure that are owned by each modeling area (Figure 3). The amount of shares for a particular ditch that are assigned to a modeling area can vary from year to year enabling users to evaluate the impact of leasing water in certain years. In the event that the user has headgate diversion records, these can be entered for each modeling area.

For groundwater pumping, users may enter monthly groundwater pumping, or if the user only has total annual pumping, the model has the ability to distribute annual pumping into monthly values for agricultural and non-agricultural wells.

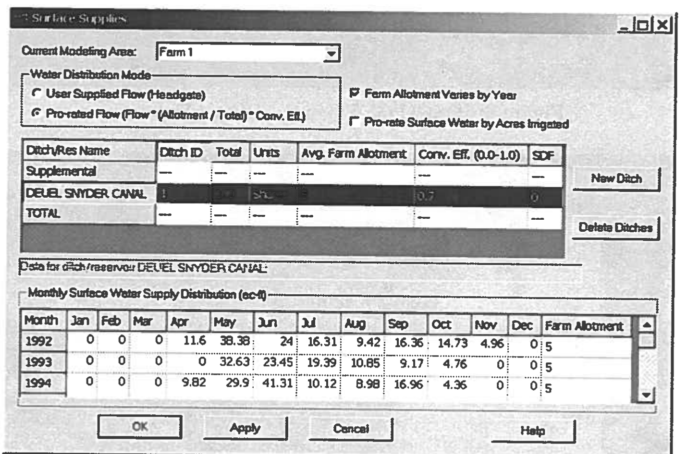

Figure 3: IDSCU GUI for Surface Supply Options

QUANTIFICATION OF DEPLETION OF GROUNDWATER

After obtaining an estimate of the water demand and supply, the IDSCU model can compute depletions of both surface and groundwater (Figure 4). Users may evaluate the impacts of the groundwater depletions by examining whether the groundwater is a primary or suplemental source of water and by examining well efficiency using a “Presumptive Depletion Factor” (PDF). The model also can compute groundwater depletions based on a water budget as shown in Figure 5.

Results may be plotted with the click of a button using the IDSCU Model's built-in graphics package (Figure 6). Users may compare the results of CU of groundwater based on a water budget versus well efficiency multiplied by well pumping to evaluate if the two results are in general agreement.

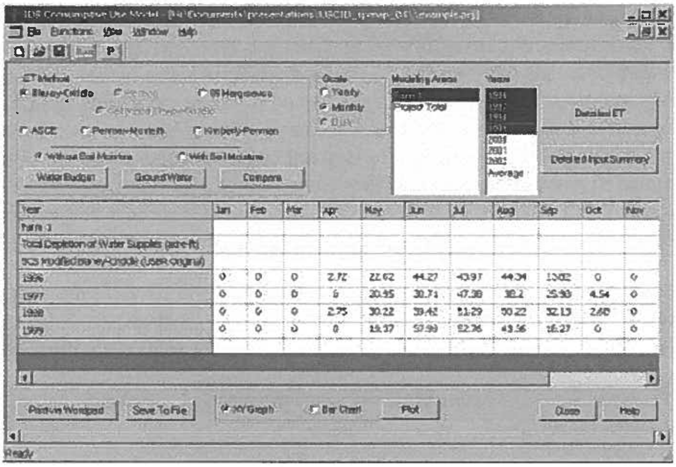

Figure 4: IDSCU GUI General Output Screen.

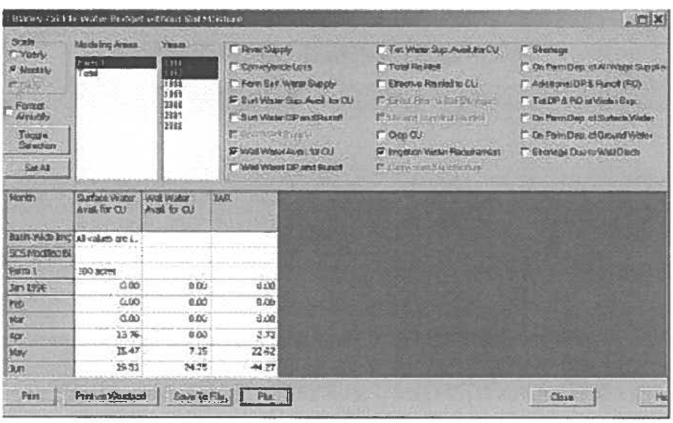

Figure 5: IDSCU GUI for Water Budget Output Screen.

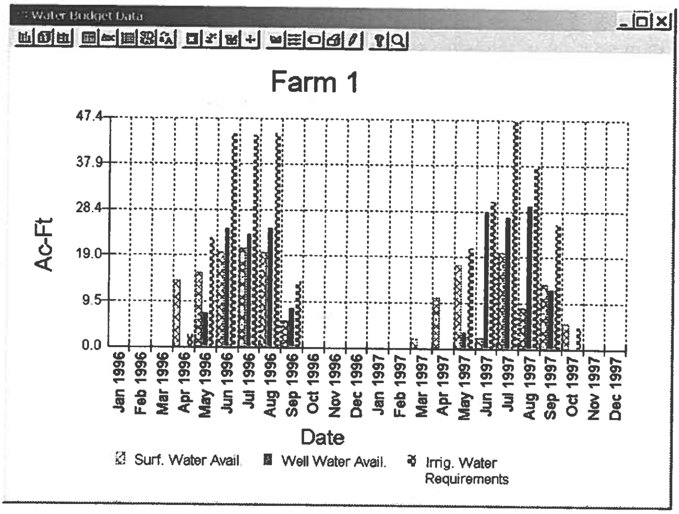

Figure 6: IDSCU GUI Water Budget Sample Plot.

QUANTIFICATION OF AUGMENTATION REQUIREMENTS

Colorado water managers need to determine the lag time from when a well is pumped or water is recharged to a recharge site and when a depletion or accretion happens in the river. Historically the Stream Depletion Factor (SDF) (Jenkins, 1968) methodology has been used in Colorado to determine the impact of the depletions of groundwater on a particular stream, and the IDS Group has developed the SDF View model to calculate monthly depletions or accretions (in the case of recharge sites) using the SDF methodology. However, the SDF methodology is an analytical technique based on several boundary assumptions. Although analytical techniques are convenient and, if properly calibrated, very valuable tools, they are not able to handle the heterogeneity of an aquifer. Models were needed to support the use of other analytical techniques that have different boundary conditions (no flow boundaries, alluvial aquifers, etc.).

In order to meet additional needs expressed by water users, a new model based on the State Engineer's Office system was implemented by the IDS Group in the past year. This model is called the IDS Alluvial Water Accounting System (IDS AWAS). This new model has the capability of modeling different time steps (daily, monthly, and annually) and allows users to evaluate different types of boundary conditions. Figure 8 shows the IDS AWAS input screen. Figure 9 and 10 shows IDS AWAS output, in tabular and plot forms.

The IDS Group's work in the South Platte is one framework for the development and implementation of decision support tools to assist water managers. There continue to be opportunities for updating the current methodology used for calculating augmentation requirements. Fertile areas for ongoing research include developing, maintaining, updating, and deploying DSS.

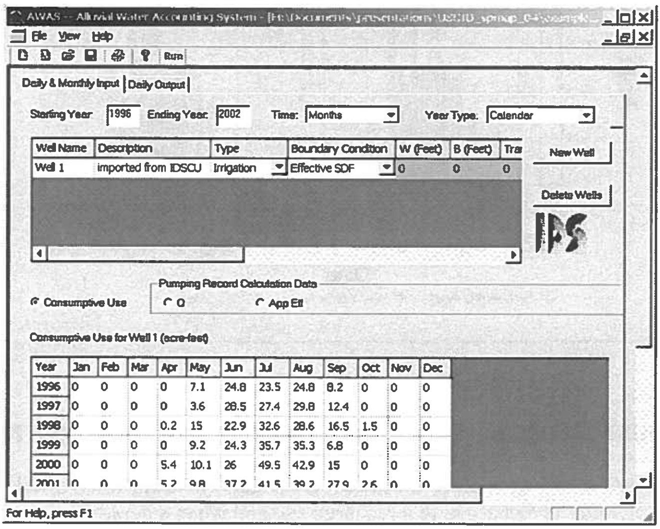

Figure 8: IDS AWAS GUI Input Screen.

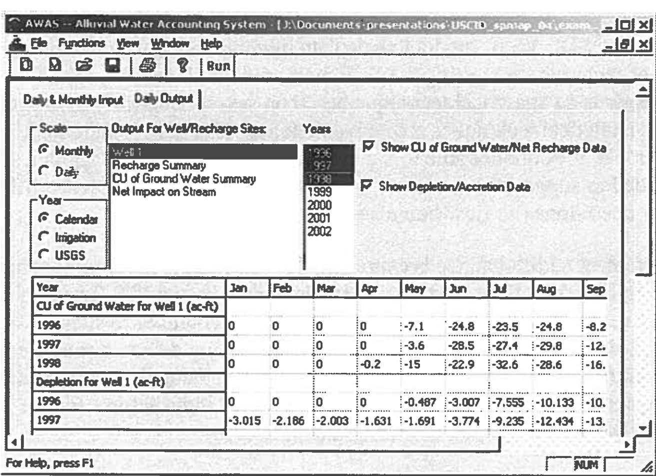

Figure 9: IDS AWAS GUI Output Screen.

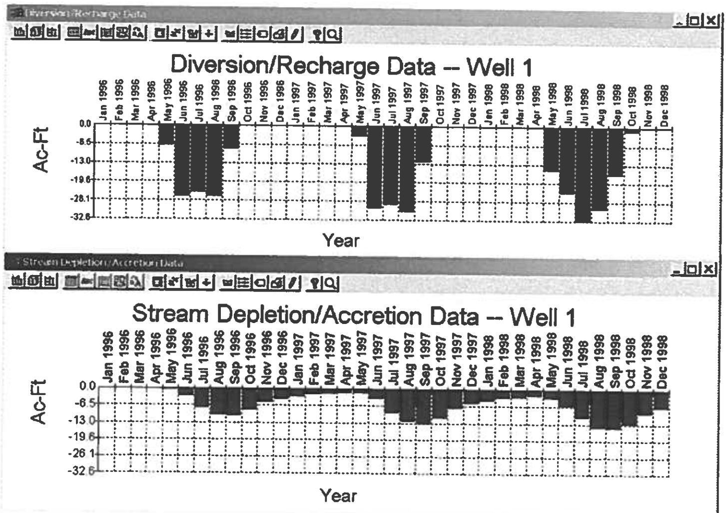

Figure 10: IDS AWAS Output Sample Plot.

SOFTWARE DEVELOPMENT APPROACH

Building on good communication with water users, the IDS Group adopts a user-centered approach to Decision Support System (DSS) development. Using this approach ,we have developed several data driven tools that are widely used in the South Platte and other parts of Colorado. These tools are collectively called the "South Platte Mapping and Analysis Program" (SPMAP) (www.ids.colostate.edu/projects/splatte).

The SPMAP tools include a GIS tool, a tool for calculating CU, and a tool for calculating depletions to an aquifer. The GIS tools can be used to determine the location and size of irrigated lands, groundwater wells, weather stations and other data important for determining consumptive use for an area. This data can then be used to run the IDSCU Model to estimate CU as well as groundwater withdrawals to meet crop water needs. The CU withdrawals by pumping can then be exported to IDS AWAS, which can estimate the impact groundwater pumping will have on the river. SDF View or IDS AWAS can also be used to determine the effects of groundwater recharge on the river. They provide a comprehensive and flexible approach to meeting the modeling needs of water managers on the South Platte River.

At each major stage of development, the software is provided to the participating organizations via the World Wide Web along with on-line documentation and hardcopy documentation that can be downloaded and printed from the internet.

To make the programs easier to use and provide new options for building input files and viewing output, Graphical User Interfaces (GUIs) are constructed in Visual C. The development and user platform is a PC running Windows 95/98/NT/2000. Development has proceeded by using a "modular" approach, meaning tools can be used as stand-alone components or used in tandem. New components and tools can be substituted or added to the system with minimal changes to the other components or the data storage.

User documentation for the software is available on the internet and can be accessed from Help menus in the model interfaces. The combination of using developed models, building graphical interfaces, using Avenue scripts, following a modular approach and developing good documentation makes this software flexible, generalized, and easy to use.

UTAH'S TRI-COUNTY AUTOMATION PROJECT

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ABSTRACT

This paper discusses an ongoing technology project in the tri-county area of central Utah (Carbon, Emery, and Sanpete Counties; see Figure 1). The three counties share the same watershed (Wasatch Plateau) even though Carbon and Emery are in the Green/Colorado River drainage and Sanpete is in the Sevier River drainage. The county boundaries roughly equate to river basin boundaries: Emery—San Rafael River; Carbon—Price River; and Sanpete—San Pitch River.

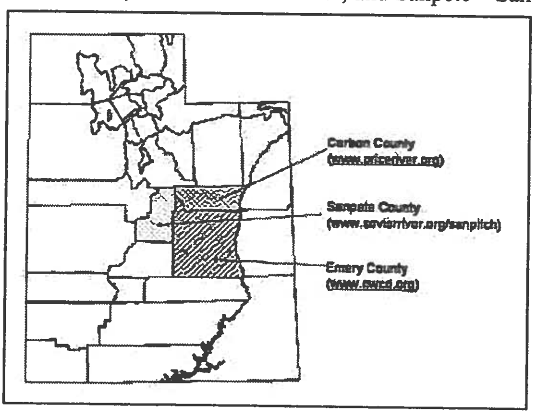

Figure 1. Tri-County Area

There are 13 small trans-basin diversions that export water from Emery and Carbon Counties to Sanpete County. There is a Federal water project in each county and Colorado River salinity projects in Emery and Carbon. And there is a myriad of contentious issues developing including: protecting and quantifying water rights, a leaky reservoir basin which has become an unintentional trans-

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basin diversion, a proposed new trans-basin diversion which is in the final planning stages, quantifying the impacts of the Federal salinity projects, conjunctive use of Federal and non-Federal facilities, and addressing fish and wildlife issues.

Part of the solution to avoiding future conflicts in the tri-county area involves increased real-time monitoring and control, and using this information to operate both Federal and non-Federal facilities in an optimal fashion to the benefit of all. The existing (but still evolving) Emery County real-time monitoring system and real-time web site (www.ewcd.org) are demonstrating what is possible (Emery WCD and Reclamation, 2003). Officials in all three counties are indicating strong support for a multi-county system which would cover the entire area. Emery is so committed to the concept that, several years ago, the county raised its *ad valorem* tax to provide base-level funding for their portion of the project (Hansen and Berger, 2003).

BACKGROUND ON THE FEDERAL WATER PROJECTS

Reclamation's first construction efforts in the tri-county area date back to the Great Depression; its most recent construction activities were in the 1960's. The three Reclamation projects provide supplemental irrigation water, with the Emery County Project providing some water for industrial use and the Scofield Project providing flood protection.

The completion of a railroad through Sanpete County contributed to growth in the Ephraim and Spring City area. When the San Pitch River could no longer provide a dependable full-season irrigation supply, Reclamation began an investigation in 1931 to develop additional water sources. Started in 1935, the Sanpete Project was completed 4 years later. It features two small tunnels that transport water from the San Rafael River (a tributary of the Green River) on the east side of the Wasatch Plateau, to the valley farmland on the west (in the San Pitch/Sevier drainage). Today the project features are operated by the Horseshoe and Ephraim Irrigation Companies.

Started during World War II, the Scofield Project was completed in 1946. Reclamation's Scofield Dam on the Price River (a tributary of the Green River) was initially constructed to protect the Denver and Rio Grande Western Railroad tracks, a state highway, telephone and telegraph lines, and several coal mines from potential flooding. The project now provides seasonal regulation of the Price River for supplemental irrigation to the lands around Price, as well as flood protection. The project is operated by the Carbon Water Conservancy District.

Located just south of the Scofield Project, in the San Rafael River Basin, the Emery County Project provides supplemental irrigation water to the lands around Orangeville, Castle Dale, and Huntington. The project includes two reservoirs, a diversion dam, two canal delivery systems, and land drainage features. The irrigation facilities were completed in 1970. After construction, the project was altered to provide water for coal-fired power plants in the county. The project is operated by the Emery Water Conservancy District.

The operating entities on all these projects are small compared to other Reclamation projects. Each struggles to operate its project 24/7 in an optimal manner. Technological innovations promise some relief.

WEB-ENABLED MONITORING NETWORKS

To better manage the three Federal water projects, plus all the pre- and post-projects, a web-enabled real-time monitoring system is developing in the tri-county area. This monitoring system is taking advantage of the rapid changes occurring in the technology arena.

We live in an increasingly interconnected world. Water information is being collected from watersheds and service areas, and being transmitted to water district offices, canal company staff, river commissioners, etc. A water manager can access sensors and gate actuator data in remote locations to see what is happening and make the necessary changes; a technologist can troubleshoot an automation problem at a site distant from his or her PC. The issue has become, how do we make all this information, from different devices and transmitted in different protocols, accessible to all the people who need it?

The Web provides an ideal graphical user interface (GUI) for water resource applications. Because of its standardized and portable nature, the Web's various components allow us direct access to information from a variety of computing platforms, from desktop PCs to cell phones. Web page designers can embed programming and algorithms into the pages themselves. The server (the computer that serves Web pages) can communicate directly with embedded applications. All of these capabilities allow for development of complex data-driven pages to present essential and timely information, without information overload and without having to create custom applications. To understand how this applies to water resource application, view the situation in Emery County.

EMERY'S REAL-TIME MONITORING SYSTEM

In 1993, with funding provided by a drought-program grant from Reclamation, the Emery Water Conservancy District (District) designed and installed the first step in a comprehensive real-time hydrologic and weather monitoring system. This system was designed to improve the responsiveness of the county's delivery systems. Data from the field sites was telemetered back to the District's office by line-of-sight radio. The field monitoring sites fell into four general categories: the San Rafael River and its tributaries, canals (largely at diversions), springs critical to Emery County's municipal and industrial (M&I) water supply, and weather stations. In this initial effort, 17 water and 3 weather monitoring sites were upgraded to real-time.

The initial effort has expanded in subsequent years. The District now has a monitoring system covering western Emery County that includes 80 field sites (see Table 1), 5 repeaters, and a base station (Humphrey, et al., 2002). The system also includes an early warning system on Joes Valley Reservoir and 3 fully-automated cloud-seeding sites. All these activities have similar equipment to facilitate operation, maintenance, and repairs (OM&R).

Table 1. Real-Time Monitoring Sites Identified by Type and Drainage (2002)

Type of Site	San Rafael River Huntington Creek	San Rafael River Cottonwood Creek	San Rafael River Ferron Creek	Muddy Creek	Total
River/ Reservoir	8	8	3	2	21
Canal	12	10	3	0	25
Spring	8	10	3	6	27
Weather	1	4	2	0	7
Total	**29**	**32**	**11**	**8**	**80**

The District's real-time monitoring system generates a great deal of information, much of it useful to organizations other than the District. There was a continuing concern about the best and most efficient method to dispense the data. At the recommendation of a local consulting firm, StoneFly Technology, it was decided to dynamically connect the environmental monitoring system to the District's website (www.ewcd.org).

In 1999, a first attempt was made at using the District's website to distribute the county's real-time information. The website was modeled after a successful site that was developed for Utah's Sevier River Basin (www.sevierriver.org) (Berger et al., 2001). The Emery website has been so successful that it is continually expanding. A popular feature of www.ewcd.org is the six webcams (one pan-tilt-zoom or PTZ). The website displays live still images (updated every 10 minutes) from cameras located throughout the county, including 14 views from the PTZ on the Swasey Diversion Dam.

Since 1993 the base station for the District's system has also evolved. The first unit was a PC running DOS and the datalogger vendor's software. The current base station includes: (1) router/firewall which secures the real-time system; (2) a switch which routes network communications; (3) an ADSL modem which connects to the upstream Internet provider: (4) a file server running Windows

2000 Professional which polls the datalogger and stores the real-time data to disk; (5) a mirror data storage system located in an adjacent building; (6) dual web servers running Redhat 7.3 Linux which provide web/e-mail/DNS hosting for www.ewcd.org; (7) a healthy UPS with web-based management; and (8) a diesel-powered backup generator.

The Emery County monitoring system has proved to be successful. According to the Utah State Water Plan (Utah Division of Water Resources, 2000, p. 6-10): "The District's installation of real-time monitoring . . . has helped to make the water supply more efficient. This could be critical, especially during the inevitable dry years. There will be savings in the cost of water management." Ways the real-time system has helped conserve water and improve crop yields include: (1) faster reaction to changing hydrologic and weather conditions; (2) more frequent fine tuning of gate settings; (3) ease of trouble shooting when water deliveries are reported to be incorrect; and (4) improved ability to get water to the end of delivery systems.

The tri-county area is currently in the 6th year of a difficult drought. Emery's major storage reservoir was at record lows during the 2003-04 winter. The county's real-time monitoring system and website have proved to be an invaluable asset for managing the limited water available. But realistically, Emery's real-time system is still in its infancy.

With funding provided through the Department of Commerce's Technology Opportunities Program (TOP), the District is pursuing additional uses for its real-time monitoring network. One such use is encouraging tourism. A webpage was developed to report real-time conditions at Huntington Lake State park, located adjacent to an Emery County Project reservoir (see Figure 2). Similar pages are being developed for the area's other major tourist attractions.

HUNTINGTON CREEK

The possibilities for a real-time monitoring system were recently highlighted by events in the Huntington Creek sub-basin of the San Rafael River (Emery County). In the 1970s, PacifiCorp (formerly Utah Power) constructed a reservoir (Electric Lake) in the upper reaches of Huntington Creek to provide water to one of its coal-fired power plants. Recently the reservoir basin has started to leak; it is hypothesized that the water is being collected in an adjacent coal mine and part of it is unintentionally being exported to Carbon County. This has put pressure on the other Huntington Creek water users and threatened the Federal water right associated with the Emery County Project. At a recent well-attended meeting of all the parties involved, it was agreed that an intensive real-time monitoring and reporting system is needed, and that decision-support models could further enhance river operations. All parties agreed to cooperate and cost-share in the project. The system is being integrated into www.ewcd.org (see Figure 3).

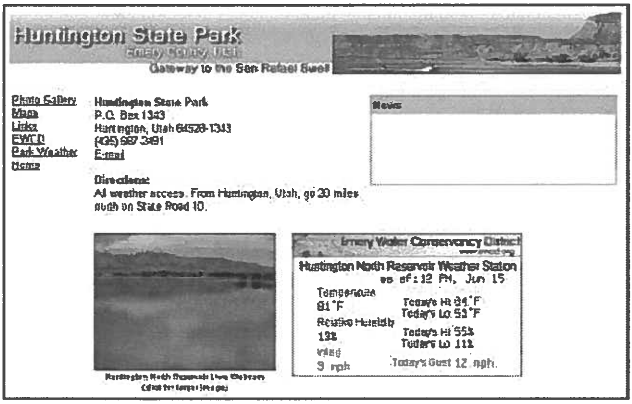

Figure 2. Web page highlighting the real-time environmental conditions (including line image) at Huntington Lake State Park. (www.ewcd.org/huntington_park)

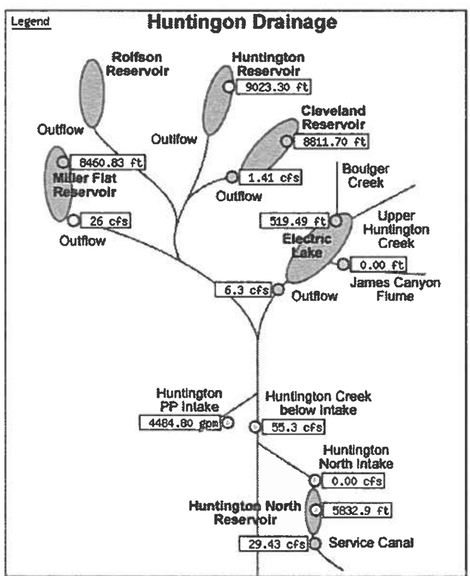

Figure 3. Schematic for reporting real-time hydrologic conditions on Huntington Creek (www.ewcd.org/Huntington_drain)

During the winter of 2003-04 additional monitoring stations were added to the Huntington Creek sub-basin. Software was also developed. A key component of the sub-basin's network will be the use of OpenBasin, a standardized Open Source database and website management software package (Berger and Maxwell, 2004). Also decision-support software is being developed to provide: (1) daily updates on the status of water rights, and (2) assistance with short-term reservoir releases.

An outgrowth of the ongoing efforts in Huntington Creek is a developing interest in automating key water control structures. The District has installed remote control on its small off-stream reservoir. Now the canal companies are looking to automate their high-mountain reservoirs and canal diversions. These interventions and others are being partially funded with a "Water 2025" grant from the Bureau of Reclamation.

TRANS-BASIN DIVERSIONS

There are 13 small trans-basin diversions from the upper San Rafael and Price River drainages to the San Pitch River Basin (see Table 2). It has recently been proposed that an additional, and substantially larger, trans-basin diversion be constructed. This controversial project has highlighted the existing 13 diversions. This has encouraged the counties to improve the measurement and management on some of the existing trans-basin diversions.

A first effort was made by the Horseshoe Irrigation Company when they installed a real-time monitoring station on their outlet works on the Spring City tunnel. At the same time, the Emery Water Conservancy District improved the monitoring system on the tunnel inlet. By sharing information, both groups have improved water management, and the level of trust between the two groups.

This year it is anticipated that a similar activity will occur on the Fairview Tunnel. Carbon County officials have contacted the Emery District about sharing the costs of a monitoring system on the tunnel inlet.

Table 2. Transbasin Diversions: San Rafael Drainage
to the San Pitch Basin

Diversion	Average (1941-1990) (acre-feet/year)
Price River to San Pitch River Basin	
Fairview (Narrows) Tunnel (Gaged)	2,240
Subtotal	***2,240***
San Rafael to San Pitch River Basin	
Candland Ditch (Estimated)	200
Coal Fork Ditch (Estimated)	260
Twin Creek Tunnel (Estimated)	200
Cedar Creek Tunnel (Estimated	340
Black Canyon Ditch (Estimated)	290
Spring City Tunnel (Gaged)	1,900
Reeder Ditch (Estimated)	250
Horseshoe Tunnel (Estimated)	600
Larsen Tunnel (Estimated)	690
Ephraim Tunnel (Gaged)	1,900
Madsen Ditch (Estimated)	40
John August Ditch (Estimated)	200
Subtotal	***6,870***
TOTAL	**9,110**

OTHER DEVELOPMENTS

In Carbon County, the water users are evaluating the feasibility of automating Scofield Reservoir, their principal water storage facility, which is located in the mountains, a 1-hour drive from the District office. The Carbon Canal Company has installed a real-time monitor at the head of its canal and will be installing two real-time monitors near the canal terminus this summer. The later will provide more reliable flows to irrigators at the end of the canal.

In Sanpete County, the Manti Irrigation Company is converting from an open ditch delivery system to a pressurized sprinkler system. Critical components of this new system are four small storage ponds. The irrigation company has installed a real-time monitoring and control system on each of the four ponds (see Figure 4) to help manage water deliveries.

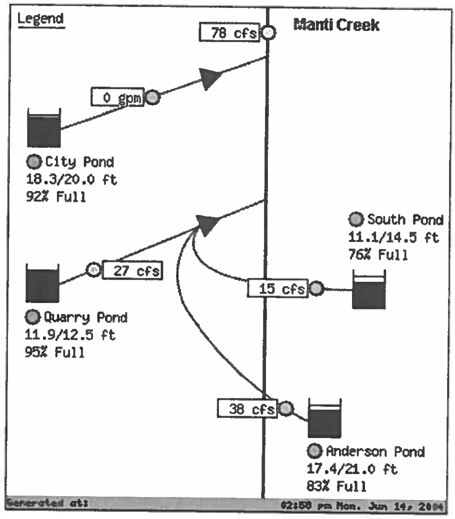

Figure 4. Schematic for reporting the status of the Manti pressure irrigation system (www.sevierriver.og/sanpitch/sf_index.php3)

CONCLUSIONS

While the automation activities in Emery County are considerably more advanced than in the other two counties, significant progress is being made in all three counties in the development of a comprehensive real-time monitoring network with accompanying websites. Not only are the counties looking at river basin management (rather than just individual projects), but they are also examining their inter-county issues. By providing information in an open fashion they are not only improving water management, but they are developing trust between all water users in the tri-county area.

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CONJUNCTIVE WATER MANAGEMENT AND TRADE OFFS BETWEEN GROSS FARM INCOME AND SALINITY

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ABSTRACT

The paper assesses the on-farm financial gains for rice growing farms through different modes of irrigation and compares them with conjunctive use of surface and groundwater. The data used in this study was collected from 544 farms located in the Rechna Doab. The results highlighted the problem of increased use of tubewell water in the saline groundwater zones that had resulted in the deterioration of the soils and groundwater quality, which has led to the problem of permanent up-coning of saline groundwater. Conjunctive water management in rice crop increased the farm income by about \$ 75.82 and \$ 172.41 per hectare compared to only using the canal and tubewell water, respectively The SWAGMAN Farm Model has also been used to evaluate the financial and environmental trade-offs for effective conjunctive water management in the Rechna Doab. The SWAGMAN Farm Model was developed by CSIRO (Australia) and was adapted for 28 sub-divisions in the Rechna Doab. Among 28 sub-divisions, this paper reports the results from three sub-divisions namely, Sheikhupura, Mangtanwala and Dhaular. The model optimization results showed that it is possible to increase the total gross margins while keeping the salinity levels and the changes in depth to water table in the acceptable limits through conjunctive water management at the sub-division level.

INTRODUCTION

Pakistan is fortunate enough because its soils, topography and climate are generally suitable for farming but its agriculture sector faces the problem of scarcity of the irrigation water. This paucity of irrigation supplies has forced the farmers to use the groundwater to augment their surface supplies. The quality of groundwater in Pakistan varies from fit for irrigation to moderately saline to sodic. Thus the tubewell owners in the marginal quality groundwater areas are bound to use the tubewell water in conjunction with the surface water on their farms. Currently the farmers are using about 65.75 Billion Cubic Meter (BCM) of groundwater in

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Pakistan (Halcrow, 2002). The international literature is filled with the studies on conjunctive water management and its impact on crop productivity and related issues [Gangwar and Toorn (1987), Bredehoeft and Young (1983); Brewer and Sharma (2000), Datta and Dayal (2000), Raju and Brewer (2000), Sakhtivadivel and Chawala (2002) and Chaudhary and Shah (2003)]. In Pakistan, the review of literature shows that all of the previous studies conducted in the arena of water management reported the management problems leading to the inefficiencies in irrigation application and reduction in crop productivity, [Kijne and Velde (1991) and Siddiq (1994)]. Few of the studies took into consideration the impact of waterlogging and salinity on productivity at the farm level [Meyer *et al.* (1996), Prathaper *et al*, (1997) and O'Connell and Khan (1999)]. None of these studies have taken into consideration the trade-offs between gross farm income, groundwater and salinity at irrigation Subdivision level. To answer the issues of spatial differences in the trade offs between gross farm income, groundwater and salinity at the irrigation subdivision level, this paper presents the results of the optimization modeling at the sub divisional level in the Rechna Doab (area between the Ravi and the Chenab Rivers). The Rechna Doab has a gross area of 2.98 million hectare (Mha), of which 2.319 Mha is the Gross Command Area (Figure 1). In the Rechna Doab, three types of irrigation sources are commonly used on farms i.e. canal irrigation, tubewell irrigation and the combination of both. Irrigated agriculture started in the Rechna Doab in 1892 via the Lower Chenab Canal. The designed cropping intensity of the irrigation system was pitched low, in the order of 60-70 percent at the start, but now the cropping intensity is more than 120 percent, indicating the increased water demand. This demand is being met through more than 180,000 tubewells in the fresh groundwater areas of the Rechna Doab (Jehangir *et al.* 2002). The physiography of the Rechna Doab consists of (a) Active flood plains, (b) Abandoned flood plains, (c) Bar Uplands and (d) Kirana Hills (longitudinal across the Doab). Regarding the groundwater quality, the Rechna Doab is divided into three distinct zones (i) Fresh Water Zone (TDS < 1000 ppm) 1.36 Mha. (ii) Mixing Zone (TDS 1000-3000 ppm) and (iii) Saline Zone (TDS > 3000 ppm) 0.198 Mha.

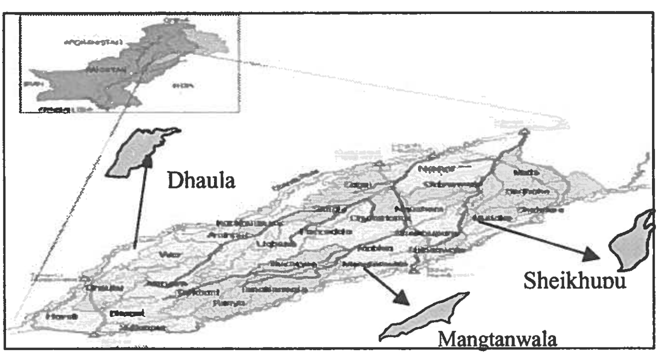


Figure 1. Study Area in the Rechna Doab, Punjab, Pakistan

The soils are tertiary in nature and have recent alluvial deposits that consist of fine to very fine sand and silt. Soils are southwesterly sloped and the slope is 0.38 meter/kilometer (m/Km) and 0.29 m/Km in the upper and lower parts, respectively. Surface salinity is found in patches covering more than 20 percent of the cultivated area in the Rechna Doab (1.17 Mha). The meaning of conjunctive water management and its scope, practices and standards vary a great deal depending on the scarcity and quality of water in the Rechna Doab. This paper also attempts to analyze the economics of conjunctive water management practices in the Rechna Doab and provide the results of the SWAGMAN Farm Model for optimal land use in three of its irrigation Subdivisions.

METHODOLOGY

Study Area

The Sheikhupura, Mangtanwala and Dhaular sub-divisions are located in the upper, middle and the tail parts of the Rechna Doab (Figure 1). These sub-divisions had 46.45, 62.91 and 65.96 thousand hectares of cultivated area, respectively. The water table depths were reported to be 2.47, 5.78 and 5.08 m in Sheikhupura, Mangtanwala and Dhaular sub-divisions respectively. Water allocation for the Sheikhupura, Mangtanwala and Dhaular sub-divisions was 1.12, 1.01 and 5.29 million mega liters (ML), respectively.

Data Collection

The primary data sets were collected through a well-designed pre-tested questionnaire, which were used to collect the information from 544 sample farms located on 188 sample sites in the Rechna Doab. Physical and meteorological data were collected from secondary sources comprised of Punjab Irrigation Department (PID), Salinity Monitoring Organization (SMO) and Meteorological Department. Physical data includes soil texture, area under different soils, textural classes and water quality. The meteorological data included information about rainfall, humidity, sunshine, wind speed and temperature. The data about irrigation, infrastructure and the designed discharges were collected from the irrigation department.

Model Specification

The SWAGMAN Farm Model is an annual model that allocates land to different crops on annual basis, based on distribution of soils on farms within sub-divisions. The model takes into consideration the potential land uses, crop evaporative requirements, current irrigation practices, leaching requirements, annual rainfall, leakage to deep aquifer, depth to water table, capillary inflow from shallow water table, salt concentration of irrigation and groundwater. It also accounts on the economic returns from potential land uses, and maximizes total gross margins for the sub-divisions subject to the given economic and environmental constraints. In the Rechna Doab, the crops sown during the Rabi and the Kharif seasons were taken into account. The major crops during the Kharif season were rice, cotton and Kharif fodder while during the Rabi season the major crops were wheat and Rabi fodder. The sugarcane was an annual crop so it was treated as such in the Model. The specification of the model is given as follows:

$$TGM = \sum_{C} \sum_{S} X_{C,S}(GMLW_{C} - IRRN_{C,S} \times WPRICE)$$

Where:

TGM	= Total gross margin ($)
X	= Area under land use C and soil type S (ha.)
GMLW	= Gross margin of a land use less cost of irrigation water ($/ha.)
IRRN	= Irrigation water used for land C and across soil types S (ML/ha.)
WPRICE	= Price of water ($./ML)
C	= Land uses under various cropping patterns in the sub-division
S	= Soil types across the farms in the sub-division

The model was subjected to the constraints namely, area, salt balance, net water balance, pumping of groundwater and water allocation. The total water requirements were not allowed to exceed the annual water allocation to the respective sub-divisions. The water allocation for a specific Subdivision was calculated by multiplying area under specific crops on different soil types and irrigation requirements on farms. The objective function was solved by using the integer programming solver GAMS, subject to given constraints. Two scenarios were generated. In the first scenario (SCN1) the actual allocation of irrigation supplies were used while the second scenario (SCN2) was generated by using the maximum surface supplies required for crop use.

RESULTS AND DISCUSSION

In the Rechna Doab, the farmers exploit groundwater to supplement canal water supplies. The quality of the groundwater differs spatially. The literature shows that groundwater of good quality is found in the upper parts of the Doab in a 24 to 48 Kilometer wide belt along the flood plains of the Chenab and Ravi rivers. Highly saline groundwater is found in the lower and central parts of the Doab. The Upper Rechna Doab contains fresh water of 500 parts per million (ppm), but in the central and lower portions, groundwater salinity concentration varies from 3,000 to 18,000 ppm. In the central and lower parts of the Doab, majority of the tubewells are pumping marginal to poor quality groundwater, especially at the tail ends of the canal irrigation system. The resource use pattern of rice and output under different types of water management conditions is presented in Table 1. The expenditure on seed and fertilizer on the farms using conjunctive water management accounted for about 14 percent of the total cost for rice production. The farms using only canal or tubewell water invested 17 percent and 13 percent of the total cost on seed, respectively. Table 1 also shows that land preparation accounts for about 16 percent of the total cost of rice production. The farmers using only canal or tubewell water invested 20 and 12 percent of the total cost on land preparation, respectively, to produce rice. While the farmers using canal and tubewell water conjunctively invested 15 percent of the total cost for land preparation. The table also reveals that aggregate resource use per hectare on rice was about $ 121 less on farms using only canal water as compared to the farms using the canal and tubewell water conjunctively. In the case of the farms using tubewell only the farmers invested $ 52 more as compared to the farms using both these irrigation sources conjunctively. The rice crop yields estimates show that it was 8 and 21 percent higher on the farms using conjunctive water management as compared to the farms using only canal irrigation or only tubewell irrigation, respectively. The estimates show that the net income was about 62 percent higher on the farms using conjunctive water management as compared to the farms using only tubewell irrigation.

Table 1.Input use and output for rice under different irrigation practices in the Rechna Doab ($/Ha)

Items	Source of Irrigation		
	Canal	Tubewell	Canal+ Tubewell
Seed	2.86	2.88	3.09
Fertilizer	28.10	40.90	37.19
Labor	23.83	30.79	26.47
Land preparation	36.57	41.93	44.10
Farm yard manure	18.47	26.71	32.00
Irrigation	5.02	136.81	81.05
Cost of chemicals	16.47	16.64	24.57
Harvesting Threshing	46.00	48.43	45.91
Total cost	177.34	345.10	294.40
Yield (Kg/Ha)	42.95	48.02	48.81
Gross income	387.10	452.97	453.67
Net income	209.76	107.88	286.33

The main findings from the SWAGMAN Farm Model application for Sheikhupura, Mangtanwala, and Dhaular Subdivisions are shown in Figures 2-5. These figures compare the actual model results with the two scenarios generated by the model. The changes in average and total gross margins, impact on salinity, changes in watertable level at the Subdivision level, due to proposed cropping patterns are presented in the following section. In the case of Sheikhupura Subdivision, the optimization results suggested by the SWAGMAN Farm Model for the cropping pattern would increase the gross margins by about 6.7 and 69.00 percent from the current level of $ 8.49 million to the expected level of $ 8.99 and $ 14.25 million for both scenarios, SCN1 and SCN2, respectively. The model results showed that the average gross margin per hectare in Sheikhupura Subdivision would increase from current level of $ 181 to $ 193.72 and $ 306.74

in case of SCN1 and SCN2, respectively. This increase in the total gross margin was resulted due to the selection of cropping rotation, which yielded maximum returns. In the case of Sheikhupura Subdivision, more than fifty percent of the area is classified as having loamy soils, and other half consists of clay loam and sandy loam soils. The major crops of the area are rice, wheat, Kharif fodder and Rabi fodder. Currently, about 9.04 thousand-hectare land is cultivated under rice-wheat cropping pattern, 6.04 thousand hectares under Rabi fodder-rice rotation, and 15.07 thousand hectares under Kharif fodder-wheat rotation. There was 0.41 thousand hectares of land under sugar cane, and 15.89 thousand hectares of land was kept fallow. In Sheikhupura Subdivision, groundwater is of good quality that is why, in spite of overall canal water shortage, rice is still cultivated in the subdivision.

The SWAGMAN Farm Model results for SCN1 suggested reducing the area under cropping patterns like rice-wheat and Rabi fodder-rice under limited water conditions to about 7.00 and 4.29 thousand hectare, respectively. Thus, allocating land to low delta cropping i.e. Kharif fodder-wheat and wheat alone to 15.86 and 18.69 thousand hectares, respectively. The model results also predicted to grow sugarcane on 0.61 thousand hectares of land, which was currently being grown on 0.41 thousand hectares. The salts brought into soils of the Subdivision by capillary upflow through irrigation, and rainfall during cropping season would be 122.85 and 202.30 thousand tons for both the scenarios, SCN1 and SCN2 respectively. Whereas, the salts removed by deep drainage in the growing season and was estimated to be about 83.80, and 182.50 thousand tons for both the scenarios, respectively. The model estimated the total salts brought into the root zone as 39.05 and 19.80 thousand tons over one year in the case of SCN1 and SCN2, respectively. The decrease in groundwater table and rise in salinity level might be due to cultivation of high delta crop like rice and Rabi fodder and contamination of soil and water from different industrial wastes.

The entire Subdivision of Mangtanwala has a mixture of medium to moderately fine soils. These soils are mainly silty clay; clay loam in abundance, while a considerable quantity of silt loam; loam and sandy loam is also present. The optimization of Model resulted in changes for the cultivated areas under different crops being raised in Mangtanwala Subdivision. This shifting of area under different crop rotations gave 6.1 and 29.36 percent increase in gross margins of The entire Subdivision of Mangtanwala has a mixture of medium to moderately fine soils. These soils are mainly silty clay; clay loam in abundance, while a considerable quantity of silt loam; loam and sandy loam is also present. The optimization of Model resulted in changes for the cultivated areas under different crops being raised in Mangtanwala Subdivision. This shifting of area under different crop rotations gave 6.1 and 29.36 percent increase in gross margins of the Subdivision, raising it from the current level of $ 16.57 millions to $ 17.59 and $ 21.44 millions for SCN1 and SCN2, respectively. The average gross margin

Figure 2. Total Gross Margin in Sheikhupura, Mangtanwala and Dhaular Subdivisions

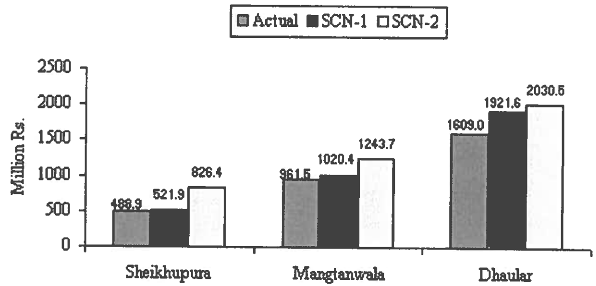


Figure 3. Change in Depth to water table in Sheikhupura, Mangtanwala and Dhaular Subdivisions

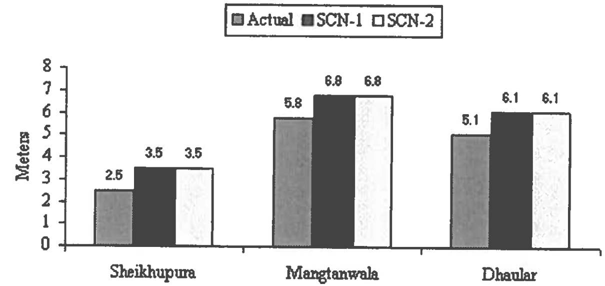


Figure 4. Impact on Salinity in SCN-1 in Sheikhupura, Mangtanwala and Dhaular Subdivisions

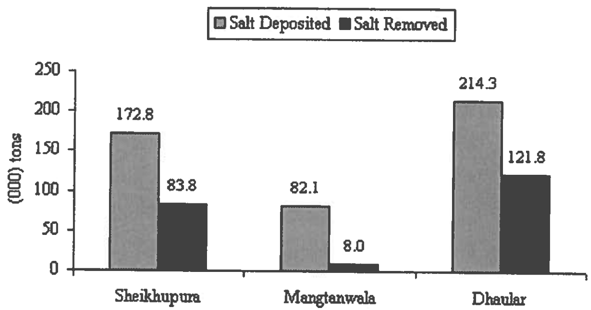
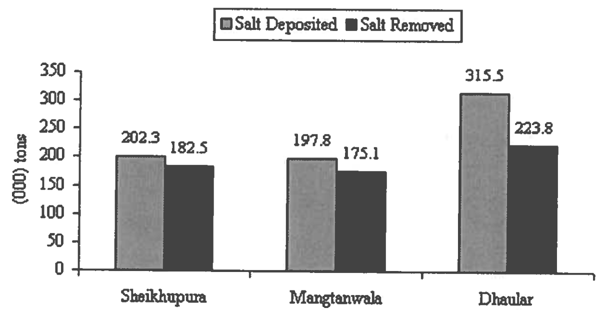


Figure 5. Impact on Salinity in SCN-2 in Sheikhupura, Mangtanwala and Dhaular Subdivisions



per hectare in Mangtanwala Subdivision increased from the current level of $ 263.5 to $ 279.64 and $ 340.84 in SCN1 and SCN2, respectively. The main crops of Mangtanwala include rice, wheat, sugarcane and fodder. At present, rice-wheat is grown under the area of about 25.68 thousand hectares followed by 13.54 thousand hectares under Kharif fodder-wheat. The sugarcane, Rabi fodder-rice and maize-wheat covered the land by 6.67, 4.67 and 2.54 thousand hectares, respectively. Remaining of the 9.82 thousand hectares was kept fallow. In SCN1, the model results showed that rice-wheat and maize-wheat crop rotations were dropped but increased the area under sugarcane and Kharif fodder-wheat by 18.50 and 15.99 thousand hectares, respectively. Due to water constraint, the model adopted wheat for 24.55 thousand hectares and reduced Rabi fodder-rice to 2.21 thousand hectares from the current area of 4.67 thousand hectares.

For the whole year, the crop water requirement of the cropping pattern proposed by the model was 408281 ML for SCN1 and 991725 ML for SCN2. The model predicted that the watertable in the Subdivision would go down to 6.78 meters from 5.78 meters, thus, falling by one meter from the current level. The salts brought to the root zone by irrigation water and rain over the year would be 82.05 and 197.80 thousand tons under SCN1 and SCN2, respectively. The rice and sugarcane in Mangtanwala Subdivision was proposed to be cultivated on a large area, and thus, use of more groundwater for fulfilling the demand of these high delta crops would lower the ground water level. As Mangtanwala Subdivision is situated in relatively fresh groundwater zone, the use of good quality of water would help to leach down the salts and reduce soil salinity.

Table 2. Land use proposed by SWAGMAN Farm Model under SCN-1 and SN2 (000 Ha)

Land use pattern	Sheikhupura		Mangtanwala		Dhaular	
	SN1	SN2	SN1	SN2	SN1	SN2
Rice-Wheat	7.00	25.46	0.00	39.46	0.11	21.44
Cotton-Wheat	0.00	0.00	0.00	0.00	10.26	10.26
Sugarcane	0.61	1.93	18.50	7.50	10.95	16.21
Kharif Fodder-Wheat	15.86	8.56	15.99	7.10	20.96	11.50
Rabi Fodder- Rice	4.29	10.50	2.21	8.85	7.74	6.55
Wheat	18.69	0.00	24.55	0.00	15.93	0.00
Fallow	0.00	0.00	1.67	0.00	0.00	0.00

Dhaular Subdivision is located in the lower Rechna Doab, and has cultural command area of 65.96 thousand hectares. The model proposed significant changes based on estimated gross margins. It predicted 19.43 and 26.19 percent increase in total gross margins through optimization of land use under different cropping patterns. Existing gross margins were estimated to be $ 27.74 million while projected gross margins would be $ 33.13 and $ 35 millions for both SCN1 and SCN2, respectively. The average gross margins per hectare were predicted to increase by the model from the actual scenario with \$ 421 to \$ 502, and \$ 530.75 in SCN1 and SCN2, respectively.

The SWAGMAN Farm Model redistributed the existing cropping patterns and their areas under cultivation. In SCN1, about 20.96 thousand hectares of land for Kharif fodder-wheat was proposed by the model, which was only 9.55 thousand hectares in the actual scenario. This major shift was due to low delta cropping pattern since water supply was equal to crop water requirement in SCN1. The model increased the area under sugarcane to about 10.95 thousand hectares, which was 3.84 thousand hectares in the existing scenario, and adopted wheat crop to about 15.93 thousand hectares. But it decreased the area under Rabi fodder-rice to about 7.74 thousand hectares, which was grown on an area of 12.73 thousand hectares. The model dropped Rabi fodder-rice in SCN1 and SCN2. In the actual scenario, there was 14.27 thousand hectares of fallow land but it dropped to zero in SCN1 and SCN2. The annual crop water requirement of the cropping pattern proposed by the model was 607099 ML for SCN1 and 947396 ML for SCN2, thus having a difference of 340297 ML. The groundwater table would fall from 5.08 meter to 6.08 meter. The model results showed that 213.7 thousand tons of salt in SCN1 and 333.51 thousand tons of salts in SCN2 would be deposited in root zone through irrigation water while the rain would add 0.59 thousand tons of salts in both the scenarios. Salts removed from root zone through deep drainage were 121.84 and 241.60 thousand tons in SCN1 and SCN2, respectively. The net additions of salts remained positive and were 92.36 and 92.50 thousand tons in both the scenarios, respectively. The increase in soil salinity was due to the pumpage of saline groundwater for rice crop.

CONCLUSIONS

In this paper, the farmer's mode of irrigation on their farms and their perception about the quality of water in the Rechna Doab is presented. The study shows that about 93 percent of the farms were using groundwater in the Rechna Doab. Among these users about 47 percent were exploiting saline and marginal aquifers. These farmers were also facing the major threat of salinity on their farms. They needed to be educated about the conjunctive use of irrigation water to minimize the effect of salinity on their farms. The above results are stark evidence of on-farm gains due to the conjunctive use of canal and tubewell water. These gains call for more efficient conjunctive water use on farms. The financial analysis showed that potential farm benefits could be 63 percent higher in case of rice provided judicious use of canal and tubewell irrigation were applied on the farms. The results of SWAGMAN Farm Model showed that the gross margins vary in different irrigation Subdivisions due to different cropping patterns, and input and output prices. In Sheikhupura (upper Rechna Doab), where groundwater is of good quality, farmers supplement canal water with groundwater, which is quite an expensive input for crop production. Therefore, the cost of production for crops go high and gross margins are very low as compared to Dhaular (lower Rechna Doab) where farmers use tubewell water in lesser quantity. The reasons for low projected salinity level in the Sheikhupura Subdivision may be due to good quality of groundwater. Secondly, in the Sheikhupura Subdivisions the model proposed rice-wheat cropping pattern, which needs more water intensively. Rice crops play important role in leaching down the salts especially if irrigation is fresh and of good quality. In Mangtanwala Subdivision the model suggested that for maximum total gross margins, 39.46 thousand hectares of land should be cultivated under rice-wheat, 7.50 thousand hectares under sugarcane, 7.10 thousand hectares under Kharif fodder-wheat, and 8.85 thousand hectares under Rabi fodder-rice cropping rotation in the case of SCN2. In the case of Dhaular Subdivision the model proposed to grow 10.26 thousand hectares under cotton wheat rotation, in both the scenarios. The area under sugarcane was increased to 16.21 thousand hectares in SCN2 from its current level of 3.84 thousand hectares.

POLICY IMPLICATIONS

In the past, government invested heavily to get rid of waterlogging and salinity menace in the Rechna Doab. Currently government is encouraging farmers to install community tubewells in the areas where the groundwater is of better quality. It is also necessary to formulate some legal framework to regulate tubewell operations in areas where the recharge problem exists. The existing institutions like the On Farm Water Management (OFWM) program may be strengthened to monitor aquifer depletion/recharge on a regular basis to ensure the sustainable supplies of groundwater in the fresh groundwater areas.

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USING HEC-RAS TO MODEL CANAL SYSTEMS

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Johannes DeVries[3]

ABSTRACT

The computer program HEC-RAS can be used to model irrigation canal systems to evaluate canal hydraulics for both steady and unsteady flow conditions. An example application is presented to illustrate how the program can be used to analyze canals with inline structures, inverted siphons, pumping plants, and turnouts. A very useful feature of the program is the ability to illustrate results graphically. For design applications alternative designs can be readily evaluated by using the program option for comparing various combinations of geometry and discharges. RAS permits the use of complex cross section shapes for both open and closed conduit sections. GIS-based maps and aerial photographs can be included with the channel geometry to present realistic depictions of canal alignments, and photographs of structures can be included with geometric data to provide visual references to these features. For unsteady flow analyses the program provides a straightforward and stable solution procedure to evaluate transient flow conditions in canals. An example of unsteady analysis described in this paper is the calculation of surge waves resulting from a pumping plant flow rejection.

INTRODUCTION

The HEC-RAS System

HEC-RAS is an integrated system of software for one-dimension water surface profile computations, and is designed for interactive use in multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphic, and reporting facilities. HEC-RAS was developed by the Hydrologic Engineering Center, a research group for the U.S. Army Corp of Engineers. The program is freely distributable and can be obtained from the HEC web site: www.hec.uasce.army.mil.

The HEC-RAS system has the capability to perform one-dimensional surface profile hydraulic analysis in both steady state and unsteady conditions.

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The steady flow computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include hydraulic structures. The effects of various obstructions such as culverts, weirs and other structures can be considered in the computations. Unsteady flow computation procedure is based on continuity and conservation of momentum. The HEC-RAS system is described in the Users Manual, Hydraulic Reference and Applications Guide HEC (2001).

Losses between cross sections in steady flow analysis are the sum of the friction losses and contraction expansion losses. In subcritical analysis, the computations start at the downstream boundary and proceed upstream. The water surface at the next cross section is computed such that the energy loss between the sections is the sum of the friction losses and the contraction and expansion losses. Friction losses are computed with a friction slope from Manning's equation and the contraction/expansion looses are computed a coefficient times the change in velocity head. The friction slope is a conveyance weighted average between the sections.

APPLICATIONS

Application of RAS to the East Branch of the California Aqueduct

The hydraulics of the East Branch of the California Aqueduct were analyzed using a HEC-RAS model (DeVries *et al.* 2004). Present flow conditions and the requirements for a proposed major capacity enlargement were modeled.

The purpose of preparing the HEC-RAS model was to 1) Evaluate the hydraulics of the East Branch canal using the data collected during the 1999 flow test, and 2) analyze the requirements to accommodate proposed enlargement flows (DWR 2002). The model results were used to review and comment on DWR design criteria, model and analysis, and evaluate existing factors influencing hydraulic conditions in the canals and associated structures, including the effect of debris and sediment. In addition, part of the model was used to undertake preliminary work on analyzing unsteady flow conditions and developing a scope of work and cost estimate for a more comprehensive unsteady flow analysis of the East Branch Canal.

Features of the East Branch Aqueduct. The East Branch Aqueduct from Alamo Powerplant to Mojave Siphon is comprised of a series of trapezoidal concrete-lined canals linked by check structures, siphons, and a pumping plant. The system is designed to convey water to State Water Project (SWP) contractors in scheduled amounts according to long-term water supply contracts.

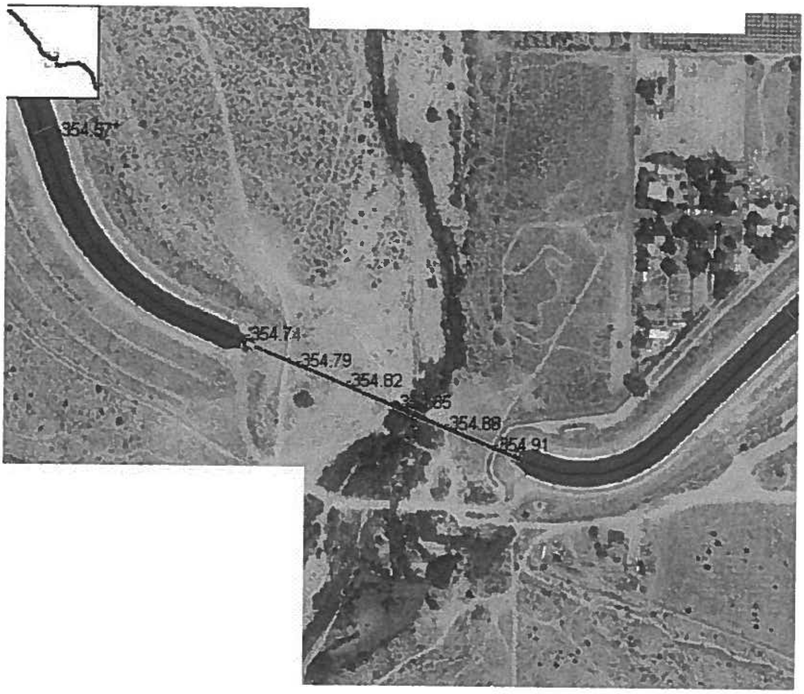

Figure 1. Typical Representation of Canal Alignment and Background Photo in the HEC-RAS Model

Aerial photos of the canal and the adjacent land were assembled into a collage to geo-reference the main physical features of the canal, as shown in Figure 1. A cascade of several hundred images that covered the East Branch Canal was downloaded from the Internet from (http://terraservice.net). For the aerial photos, these images are black and white, with 1-meter pixel resolution, and, for the quad sheets topography, the images are in color with 4-meter pixel resolution. These mosaics where combined into a single image using the MrSid compression technology. The view at every location can be zoomed in or out, depending on the amount of detail required. The sample photo in Figure 1 shows the Check 56 and Little Rock siphon structure.

Originally, DWR constructed the East Branch Canal with a capacity of 1,643 cfs (46.52 cms) at the Alamo Powerplant / Cottonwood Chute Bypass, and 1,376 cfs (38.96 cms) at Pearblossom Pumping Plant. The original facilities were designed to deliver approximately 1,000,000 acre-feet (1,233,000,000 m^3) of water annually, with provision for enlarging the system to accommodate an additional flow of 800 cfs (22.65 cms) without extensive modifications.

Development of the East Branch HEC-RAS model

The layout and geometry of the physical features of the East Branch were taken from several sources including DWR (1997), DWR (2002), a spreadsheet prepared by DWR for analysis of present conditions using data from a 1999 flow test, and engineering drawings of the structures provided by DWR. The HEC-RAS model was modified to accommodate some of the requirements of modeling the trapezoidal East Branch canal and the modifications have been included in HEC-RAS Version 3.1.

In conventional hydraulic analysis of river systems, the system is modeled starting from the downstream end and working upstream. In contrast, the longitudinal distances of the East Branch are referenced to the upstream end of the California Aqueduct as the 'mileage' refers to the distance from the start of the Aqueduct at the Clifton Court Forebay in the Delta. The difference in referencing systems for longitudinal distances was overcome by entering the East Branch mileage into the model as negative values. The approach does not affect the numerical computations of the model, but maintains the familiar reference mileposts.

The East Branch was modeled as two independent reaches, each with a specified flow distribution and downstream boundary conditions. There were 256 user entered cross sections to describe the physical system and 481 interpolated sections to get the computation distance below 1000 feet (305 m). The Check structures 43 to 66 were modeled with the "Inline Structures" option of RAS.

HEC-RAS is a generalized program that typically handles cross sections with hundreds of station elevation points and usually three Manning n values; one for the channel and one for each overbank. Canals have simpler geometry; the cross sections used to describe the East Branch pools were entered with four points and a single Manning n value. A typical HEC-RAS cross-section in Pool 43 is shown in Figure 2.

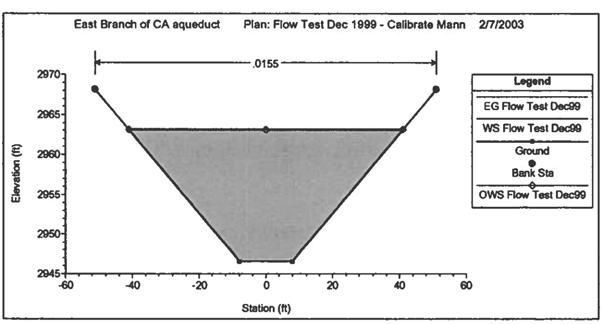

Figure 2. Typical HEC-RAS Cross Section

Two cross sections were entered for each pool, one at the upstream most point and another at the downstream end. Cross sections were then interpolated to get the computation distance less than 1000 feet (305m). Figure 3 shows the interpolation in Pool 43 from the upstream end to the first box siphon.

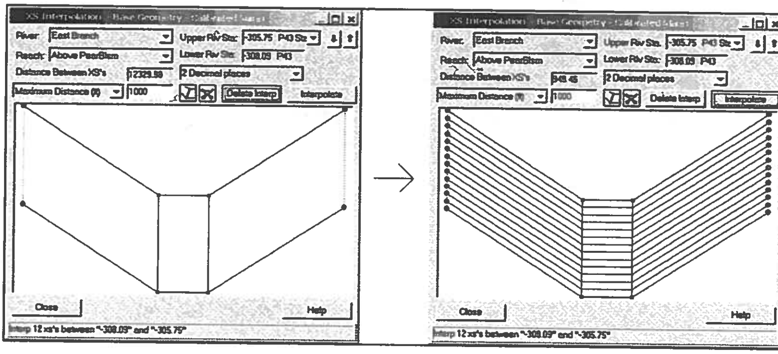

Figure 3. Interpolation of Cross Sections

The box siphons and inverted siphons were modeled as a series of cross sections with lids. This makes the computations energy based and roughly equivalent to standard culvert hydraulics without the inlet control check. The profile plot of the Myrick siphon with Check 46 is shown in Figure 4, and a cross section inside Myrick siphon is shown in Figure 5.

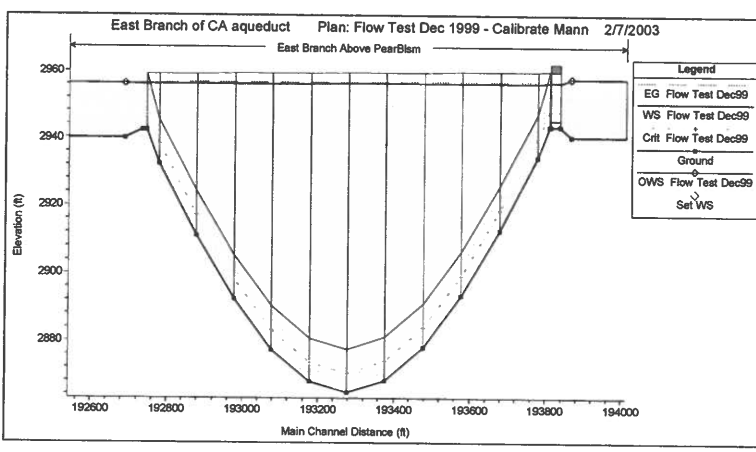

Figure 4. HEC-RAS Profile of Check 46 and Myrick Siphon

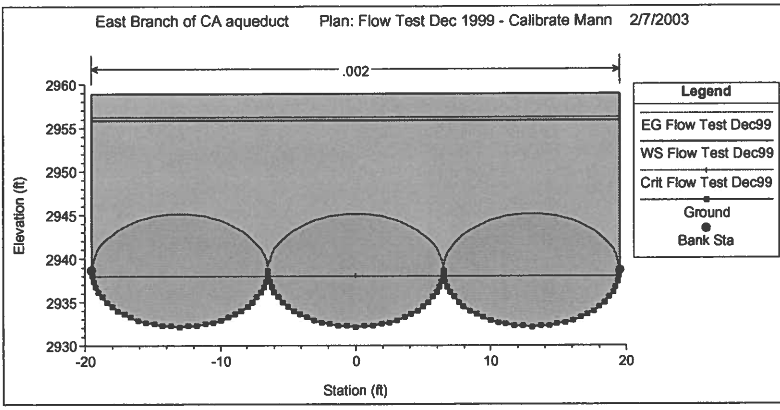

Figure 5. HEC-RAS Cross Section of Myrick Siphon

Check structures were modeled with the "Inline Structure" option. The inline structure allows for an overflow weir (not used in East Branch model) and a series of independently controlled gates. Figure 6 shows the "cross section" view of check 43 with the gates 10 feet open (3.05 m). The darker section below represents the sills and the very dark section above represents the partially closed gates.

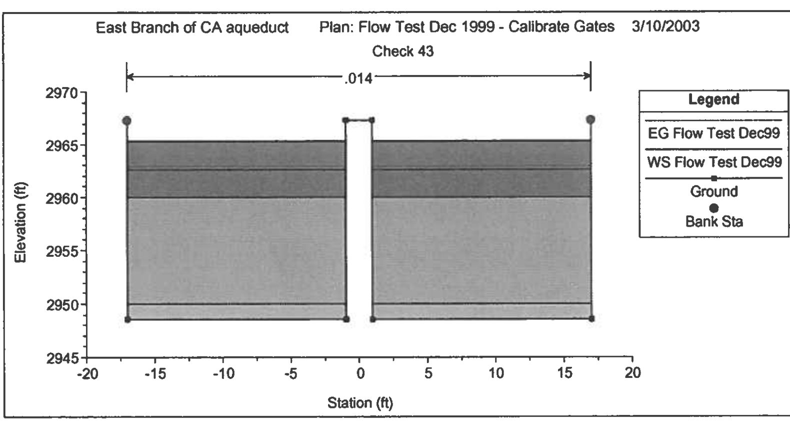

Figure 6. HEC-RAS Cross Section of Check 43

ANALYSIS

Analysis of Present Canal Performance

A flow test to determine aqueduct capacity was conducted by DWR in 1999. The flow test data were used as the water level and flow input data for the model. The water levels during the flow test were taken as the average of the water levels measured during the 2-hour data collection period while nearly steady state conditions existed. The discharge was 2010 cfs (56.92 cms) at Pearblossom Pumping Plant. The expansion and contraction loss coefficients used in analyzing the flow test data were 0.3 and 0.1 respectively. The friction loss coefficients are shown in Table 1.

Table 1. Friction Coefficients used in East Branch Model

Location	Manning n-value from calibration	Roughness height	
		k (ft)	Effective n-value
Pools	0.0154 - 0.0193		
Transition sections	0.014		
Box siphons		0.003	0.0136
Circular siphons		0.002	0.0130

The Manning n values for the transition structures and the siphons were not determined by calibration since head loss data for these structures was not available.

Calibrated Manning n-values are in the range of 0.0154 - 0.0193, these values are consistent with values observed by the USBR tests supported by Tilp (1965). A key issue with interpreting flow data is to recognize that flow and water level measurements may be imprecise, and it is necessary to carry out sensitivity analysis to determine the effects of data measurement errors on the calculations. Therefore, the HEC-RAS model was run to calculate Manning n-values for +/- 5% variation in the flow. The sensitivity analysis indicated that if flow was 5% lower, the estimated increase in Manning n-value would be about 6%. Similarly, a 5% increase in flow reduces the Manning n-value by about 4%. The Manning n values calculated by DWR are within the 5% error bands of the values calculated by HEC–RAS corroborating the different analysis method (DeVries *et al.* 2004).

Analysis of Transient Flows at Pearblossom Pumping Plant

An unsteady flow analysis was made to simulate the surges that would occur in the canal if electrical power supplied to Pearblossom Pumping Plant were suddenly cut off causing a complete flow rejection at the plant. This condition is simulated in the model by assuming the flow at the downstream end of the canal pool was decreased to zero in one minute. The initial flow in the canal is 3000 cfs

(84.95 cms) with a starting water surface elevation at the plant intake of 2941.00 feet (896.42 m).

Several conditions for reacting to this sudden canal shut down were simulated:

1. A **rapid reaction scenario** in which the gates in the check structure at the upstream end of the reach were closed starting four minutes after the power failure. The gates are closed in ten minutes assuming a linear change in flow with time. The maximum rise is to elevation 2943.55 feet (897.19 m) at about 19 minutes after plant shutdown. It is at this time that the effect of closing the check gates upstream is first experienced at the downstream end of the reach.

2. A **time delay scenario** in which the operators wait to begin the closure of the gates at the upstream check structure for 20 minutes after the power failure. The gates are closed in ten minutes.

The time delay scenario is discussed in detail below.

Time delay scenario. The scenario in which the operators wait to begin the closure of the gates at the upstream check structure may be more realistic than the rapid response case because there is often a possibility that the plant can be brought on line again without needing to shut down the system. In this case, it is assumed the canal shutdown begins 20 minutes after the power failure because it was not possible to re-start the plant. The gates are closed in ten minutes Figure 7 shows the water surface plot for this case.

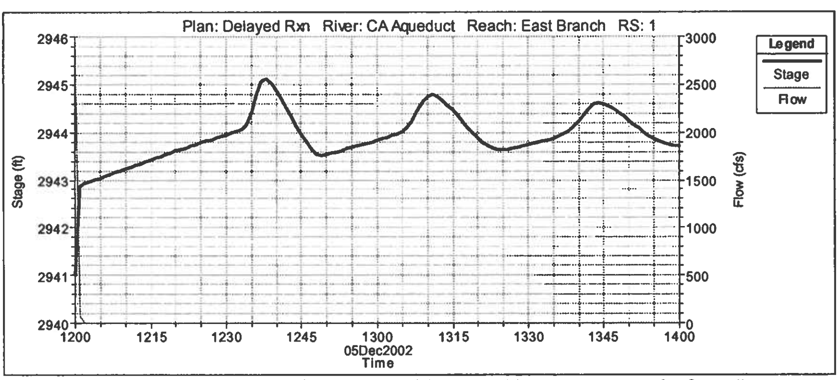

Figure 7. Transient conditions at Pearblossom (downstream end of pool)

The initial water surface is again at 2941.0 feet (896.41 m) and the initial part of the surge at the time of closure is to elevation 2942.85 feet (896.98 m). However, the flow from upstream continues at 3000 cfs (84.95) for about 20 minutes after the closure. This produces a constantly rising water surface until about 35 minutes after the positive surge was first generated. The maximum water surface rise is just over 4 feet (1.2 m) above the initial water surface.

During this time the positive wave has traveled to the upstream end of the pool. It was reflected as a positive wave at the gate and then traveled as a positive wave to the downstream end. This reflected wave causes a further rise in the water surface at Pearblossom to elevation 2945.12 feet (897.67 m) at 38 minutes after the flow rejection at the pumping plant. The water surface begins dropping at this time as a result of the negative wave produced at the upstream end of the pool.

Conditions at the upstream end are illustrated in Figure 8. The gate begins closing just about the time that the positive wave generated at the downstream end arrives at the upstream end of the reach. This can be noted by observing the simulation in profile. The negative wave produced as the gate is closing counteracts the positive wave from downstream, and this effect continues until the gate is fully closed. After this time the shape of the water surface plot is similar to that for the downstream location.

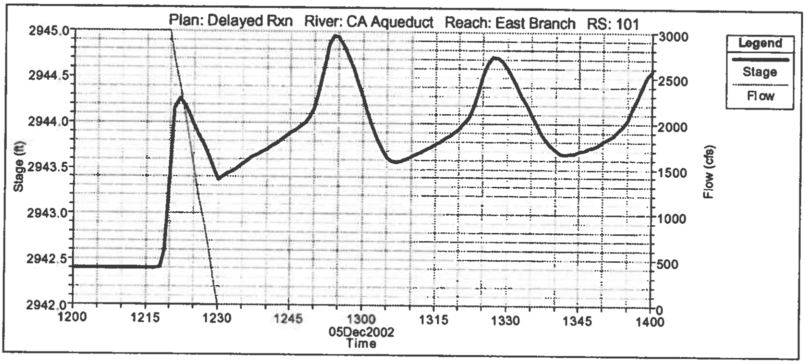

Figure 8. Transient conditions at Pearblossom (upstream end of pool) – Time delay

At the upstream end of the pool, the water surface reaches a maximum elevation of 2944.95 feet (897.62 m) about 54 minutes after plant shutdown. This is a rise of about 2.5 feet (.76 m) at the upstream end of the pool. It should be noted that a significant part of the water surface rise is due to the increase in water volume in the pool due to the delayed closure of the upstream gates.

Expansion Variations – Vertical Walls. The East Branch is being studied for a flow expansion and the RAS model can be used to evaluate various channel configurations. A good portion of the additional height needed for the expanded flows is to contain the transient waves caused by pumping plant load rejections. The expanded channel configurations discussed in this study were based on an enlargement of the trapezoidal channel. An alternative (and perhaps cheaper) expansion was evaluated that increased the channel capacity with the addition of vertical walls placed at the top of the existing channel. The vertical walls were added to the bounding cross-sections in the pool and the internal cross-sections were re-interpolated so that they would have the wall as well. The maximum difference between the trapezoidal expansion and the vertical wall expansion was 0.10 feet (.03 m) and average 0.05 feet (.015 m) for the pool.

These scenarios illustrate how the unsteady flow computation feature of the HEC-RAS model can be used to evaluate various emergency conditions in the East Branch Aqueduct. A wide variety of conditions can be modeled to assist in the formulation of emergency operation procedures and the evaluation of canal freeboard and other design consideration associated with the aqueduct enlargement.

ACKNOWLEDGEMENTS

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THE JUNE SUCKER RECOVERY IMPLEMENTATION PROGRAM: A MULTIFACETED COOPERATIVE APPROACH TO THE RECOVERY OF AN ENDANGERED FISH

Christopher J. Keleher[1]
Gene Shawcroft[2]

ABSTRACT

The June sucker (*Chasmistes liorus*) was federally listed as an endangered species in 1986. June sucker are native only to Utah Lake and are named for their annual spawning runs up the Provo River in June. Because of its importance as the specie's only known spawning location, the lower Provo River was designated as 'critical habitat' at the time of listing. The primary threats to the recovery of June sucker include: 1) Nonnative and Sportfish Management, 2) Habitat Alteration, and 3) Water Development and Operations.

Water development in the Utah Lake drainage basin has been funded and implemented primarily by federal agencies. After the June sucker was federally listed, water management agencies whose operations affected the lower Provo River found themselves in seemingly never-ending consultation under the Endangered Species Act. At the same time, the other primary threats to recovery – nonnative fish and habitat degradation – were being overlooked. Water management agencies, along with wildlife management agencies, recognized that a more balanced approach to recovery would be necessary if the June sucker was ever to be delisted.

In April 2002, the June Sucker Recovery Implementation Program (JSRIP) was formed as a partnership among federal and state agencies, local water users, and environmental/outdoor interest groups. All participants have either authority or interest in important elements of June sucker recovery. The JSRIP has two main goals:

1) Recover the June sucker so that it no longer requires protection under the Endangered Species Act.
2) Allow for the continued operation of existing water facilities and future development of water resources for human use in the Utah Lake Drainage Basin.

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Under the JSRIP, water management agencies have developed and implemented flow scenarios on the lower Provo River that mimic natural conditions while providing flexibility needed for reservoir operators. Water used for these scenarios has been acquired according to the State of Utah Water Rights Law and the June sucker is treated similar to any other water user in the system. June sucker have successfully spawned in the river under these scenarios and the numbers of spawning fish have been increasing each year. Fish reared in captivity and in refuge ponds have been stocked into the lake and are starting to turn up in the spawning runs.

Feasibility studies for the control of nonnative fish and for habitat enhancement have been funded through the JSRIP. Additional funds have been acquired for land acquisition needed to enhance habitat. Concepts are being developed for the control of problematic nonnative fish. Applied research activities to gain a better understanding of the ecology of June sucker and to guide recovery actions are being funded and implemented through the JSRIP. In addition, a communications plan has been developed to increase public awareness of the value of the recovery effort.

The recovery of June sucker is miles ahead of where it was a decade ago. Conflicts associated with implementation of the Endangered Species Act are resolved through a committee and consensus process. This presentation will focus on the development, procedural aspects and progress of the JSRIP.

INTRODUCTION

Conflicts between water development and operations in the western U.S. and the implementation of the federal Endangered Species Act (ESA) have made national headlines in recent years. Most notably, in 2002, as a result of irrigation diversions to aid drought-stricken farmers in the Upper Klamath Basin, lack of water in the lower river killed more than 33,000 migrating chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). Coho salmon in the Klamath River are protected under the Endangered Species Act as a threatened species. In July 2003, a federal judge in Oakland, California ruled that the water distribution plan for the Klamath River must be revised because it violated the Endangered Species Act by not providing sufficient water in the river for migrating coho salmon.

In 1994, water diversions left the lower Provo River in central Utah without sufficient water to support the annual spawning run of the federally endangered June sucker (*Chasmistes liorus*). Several adult June sucker died in the river. Rather than feeding the fires of confrontation, this smaller, and less publicized, fish kill has resulted in the development of a collaborative effort between water development interests and wildlife management agencies to recover the endangered fish while allowing for continued development and operation of water resources to benefit the human population.

BACKGROUND

Geographic Setting

The Utah Lake drainage is located in central Utah, USA. Utah Lake is the largest freshwater lake in the Western U.S. and covers approximately 96,600 surface acres (37,000 hectares). It is a remnant of ancient Lake Bonneville which covered most of western Utah until about 10,000 years ago. Utah Lake is fed by several streams from the east including the Provo and Spanish Fork Rivers and is drained by the Jordan River into the Great Salt Lake (Heckman and Merrit 1981).

The Utah Lake drainage provides water for the heavily populated Greater Wasatch Front. The Wasatch Front which extends from north of Salt Lake City south into Utah Valley contains over 60 percent of Utah's human population. Today, the Wasatch Front has approximately 1.8 million residents and continues to grow. The population is projected to reach 3.1 million residents by the year 2030 (Governors Office of Planning and Budget, 2003).

Water Development and Operations

Water development in the Utah Lake Basin began in the mid-1800's. In 1872, a low dam was placed across Utah Lake's outlet to the Jordan River, changing the natural function of Utah Lake to a storage reservoir. A pumping plant was built in 1902 so that lake water could be lowered below the outlet elevation. Water released from Utah Lake to the Jordan River is diverted mostly for irrigation and other uses in northern Utah County and Salt Lake County. At compromise level, a lake elevation determined through litigation between lake shore property holders and downstream water users, Utah Lake can store approximately 870,000 acre-feet of water. Approximately 710,000 acre-feet is considered active storage – water that is accessible to outlet pumps. The Provo River is the largest tributary to Utah Lake (Utah Department of Natural Resources 1997).

The Provo River Project, constructed in the late 1930's, is a transbasin diversion project that diverts water from the Duchesne and Weber River Basins. Water is delivered to supplement irrigation of about 48,100 acres of land and for municipal and industrial water for communities along the Wasatch Front in the Bonneville Basin.

The Bonneville Unit of the Central Utah Project (CUP) was authorized for construction in 1956 and is the most comprehensive of the six units of the CUP. Its purpose is water collection and storage in the Duchesne River Basin for distribution to the Bonneville Basin. While authorized to annually divert and deplete over 143,000 acre-feet of Duchesne River Basin water, the Unit has yet to divert the full amount of its entitlement. Construction began in 1967, and is ongoing. The Bonneville Unit contains the following systems: Starvation Collection System; Strawberry Aqueduct and Collection System; Municipal and Industrial System; and Diamond Fork System. These systems work together to provide water from the Duchesne River Basin to Salt Lake and Utah Counties as well as supplemental irrigation water to Summit and Wasatch Counties.

Storage in Strawberry Reservoir, in the Duchesne River Basin, supports extensive development in the Bonneville Basin. Jordanelle Reservoir, located on the Provo River above Deer Creek Reservoir, is a major feature of the Municipal and Industrial System and stores Provo River water that historically flowed into Utah Lake. Utah Lake water is replaced by transbasin releases from Strawberry Reservoir to Utah Lake, project return flows to the lake, water right acquisitions in Utah Lake, and flows that are surplus to Utah Lake rights (Working Group on the Endangered Species Act and Indian Water Rights. www/doi.gov/feature/es_wr/casestudy.htm).

In order to provide adequate water supply for Jordanelle Reservoir, 84,510 acre-feet annually is "exchanged" from Utah Lake to Jordanelle Reservoir. This exchange simply means that water which formerly flowed to Utah Lake is now impounded on the Provo River at Jordanelle Reservoir. In order to facilitate this exchange water is released from Strawberry Reservoir down Diamond Fork System and back to Utah Lake, replacing Provo River water stored in Jordanelle Reservoir.

June Sucker Biology and Federal Listing

The June sucker is endemic to the Utah Lake system and was federally listed as an endangered species with critical habitat in April 1986 (51 FR 10857). Factors contributing to the endangered status include habitat alteration, impacts from water development, and predation and/or competition with nonnative fish. The species was listed as endangered due to its localized distribution, failure to recruit new adult fish to the population and because of threats to its continued survival. The U.S. Fish and Wildlife Service (Service) designated the June sucker a recovery priority which applies to a species with a high threat of extinction, a low recovery potential and the presence of conflict (U.S. Fish and Wildlife Service 1999). Critical habitat was designated as the lower 4.9 miles (7.8 km) of the Provo River – the only known spawning location for the species.

As is the case with many threatened and endangered species, the June sucker generated little attention from the scientific community or wildlife agencies prior to its threatened status. Consequently, little was known about the life history and general biology of the species at the time it was listed. The wild population was estimated to be less than 1000 individuals making it difficult to gain basic biological information essential for recovery efforts.

The Provo River is the only Utah Lake tributary used by spawning June sucker. Fish begin moving into the river in May and spawn between the latter part of May and the end of June, depending on river conditions. Adult June sucker return to Utah Lake soon after spawning. Egg development time ranges from 10 to 20 days depending on water temperature (Shirley 1983, Modde and Muirhead 1990, Gutermuth and Lentsch 1993). Larval June sucker drift down the Provo River shortly after hatching (Radant et al. 1986, Modde and Muirhead 1990); however, no young-of-year June sucker have been found in Utah Lake. Of 53,364 young-of-year fish collected in the most recent fish inventory of Utah Lake, none were June sucker (Radant and Sakaguchi 1981). Juvenile June sucker measuring approximately eight inches (203 mm) on average have been stocked into Utah Lake and have survived and returned to the Provo River spawning run. Successful spawning in the Provo River combined with the return of stocked individuals provides evidence that the "bottleneck" in the life cycle for June sucker is at the early life stages after hatching.

Endangered Species Act Consultation History

As a result of the federal listing of June sucker as an endangered species, federal water projects were required to consult with the U.S. Fish and Wildlife Service (Service) under Section 7 of the ESA if the project had the potential to jeopardize the continued existence of June sucker. Informal consultation actually began prior to the specie's listing.

The U.S. Bureau of Reclamation (Reclamation) was informed by the Utah Division of Wildlife Resources (Division) in mid-February 1979 of the tentative taxonomic verification of the June sucker. The taxonomy of the fish was still uncertain and the Division was requested to develop a proposal for further work. The evaluation of specific project impacts on reproductive success of this species in the Provo River and development of a mitigation plan was deferred until completion of the study. Unknowns relative to spawning habits and other requirements for this species precluded making conclusions concerning project impacts.

In 1982, the Service published a notice in the Federal Register that it would review the status of the June sucker and requested information related to the species. Ultimately, on April 30, 1986, the June sucker was officially listed as endangered (51 FR 1087). Also, in 1986, the Service issued its determination of no effect for the Municipal and Industrial System of the Bonneville Unit of the Central Utah Project, but requested that enhancement opportunities be considered. As quoted from the memorandum to Reclamation's Regional Director from the Service's Endangered Species Office Field Supervisor: "The rather significant reduction in spring discharges could have negative impacts on the June sucker which are not apparent with our current level of knowledge. Therefore, it is important that the alterations associated with the project be monitored to assure that our current conclusions are in fact correct and borne out through observation before and with the project in place."

The Service concurred with a no effect to June sucker on five different consultations on federal water projects between the time of listing and 1994. In 1994, however, the Service released a Biological Opinion for the Provo River Project which stated "it is the Service's biological opinion that the Project, as operated, is likely to jeopardize the continued existence of the June sucker . . . and is likely to destroy or adversely modify designated critical habitat." It was in the 1994 spawning run that several adult June sucker died in the lower Provo River as a result of insufficient flows through critical habitat. Conservation measures identified in the reasonable and prudent alternative for the Provo River Project were "primarily based upon the establishment and protection of flows in the Provo River to ensure annual river flushing, support adult spawning activities, and maintain high quality egg and larval habitat conditions." (U.S. Fish and Wildlife Service 1994).

The Central Utah Project Completion Act (CUPCA) was passed in 1992 as part of Public Law 102-575. The CUPCA legislation transferred responsibilities for the Bonneville Unit of the CUP from Reclamation to the Central Utah Water Conservancy District (District). In 1999, the Service issued a Biological Opinion on the Diamond Fork System of the Bonneville Unit of the CUP which stated that "after reviewing the current status of June sucker, the environmental baseline for the action area, the effects of the Bonneville Unit, and the cumulative effects, it is the Service's biological opinion that the Bonneville Unit, as proposed, is not likely to jeopardize the continued existence of the June sucker, and is not likely to destroy or adversely modify designated critical habitat. The finding of "not likely to jeopardize" is based on the commitment of the joint-lead agencies to implement the conservation recommendations which have been included as part of the proposed action (U.S. Fish and Wildlife Service 1999b). Among the conservation actions identified were that the joint lead agencies (District, Department of the Interior, and Utah Reclamation Mitigation and Conservation Commission) would: 1) participate in the development of a Recovery Implementation Program for June sucker; and, 2) any future development of the Bonneville Unit of CUP would be contingent on the RIP making sufficient progress towards recovery of June sucker.

THE JUNE SUCKER RECOVERY IMPLEMENTATION PROGRAM

Development and Procedures

Because future development of the Bonneville Unit of CUP was contingent on the development of a recovery implementation program, and on making sufficient progress towards June sucker recovery, water management agencies took an active role in the development of the June Sucker Recovery Implementation Program (JSRIP). An Organization Committee of potential partners to the JSRIP was formed in 1998 to develop operational procedures for the JSRIP and to draft a Program Document. In April 2002, the JSRIP was formally adopted by the following partners: the Service, Department of the Interior, Reclamation, District, Utah Reclamation Mitigation and Conservation Commission, Utah Department of Natural Resources, Provo River Water Users Association, Provo Reservoir Water Users Company, and Outdoor and Environmental Interests.

The purpose of the JSRIP is to implement the June Sucker Recovery Plan (Recovery Plan), which was finalized by the Service in 1999 (U.S. Fish and Wildlife Service 1999), while balancing and accommodating water resource needs for the human population. The JSRIP has the following two goals:

Goal 1. To recover June sucker so that it no longer requires protections under the ESA

Goal 2. To allow continued operation of existing water facilities and future development of water resources for human use

The JSRIP functions under a 2-teired administrative structure. An Administration Committee is served by two subcommittees, the Technical Committee and the Local Advisory Board. A Program Director's Office manages the Program and also serves under the Administration Committee. The primary responsibility of the Administration Committee is to oversee and administer all elements of the JSRIP, including the subcommittees, the Program Director's Office, JSRIP funding and budget, and Program participation and operations. The Technical Committee has the primary responsibility of providing recommendations to Administration Committee and the Program Director's Office on all technical issues. Although the JSRIP is still working on the development of the Local Advisory Board, the intent is that this board would have the primary responsibility of providing a means and opportunity for local involvement in the JSRIP. All JSRIP committees operate by a consensus vote of JSRIP partners.

The Program Director's Office consists of a Program Director and staff as recommended by the Program Director and approved by the Administration Committee. The Program Director and staff are responsible for coordinating recovery activity implementation, planning and evaluating progress, monitoring and tracking the JSRIP budget and accounts, providing staff assistance to JSRIP committees, and coordinating technical review for the JSRIP.

Three documents: 1) 5-Year Strategic Plan; 2) Program Guidance; and, 3) Annual Work Plan, direct JSRIP planning. The 5-Year Strategic Plan identifies and prioritizes actions that could be accomplished in a five year period. The Annual Work Plan specifically identifies recovery actions to be taken for the upcoming operational year (January 1 to December 31). Program Guidance for the year following the Annual Work Plan provides direction and prioritization for recovery actions. Program Guidance becomes the annual Work Plan once proposals, scopes of work. And funding for a given year are finalized.

Achieving Recovery and Progress to Date

The Service has recently reappointed a June Sucker Recovery Team (Recovery Team) which functions independent of the JSRIP and reports directly to the Service's Regional Director in Denver, Colorado. A major purpose of the Recovery Team is to define recovery for June sucker that satisfies the five factors in Section 4(a)(1) of the ESA, and the definitions of endangered and threatened in the ESA. The Recovery Plan (U.S. Fish and Wildlife Service 1999) provides delisting and downlisting criteria; however, it does not provide quantifiable goals for population size or demographics. The Recovery Team also assists the JSRIP by providing recommendations to the Program Director's Office for JSRIP planning and Program Guidance.

For the purpose of the JSRIP, recovery actions identified in the Recovery Plan (FWS 1999) were grouped into six general categories referred to as recovery elements. Recovery elements were established to organize recovery actions by the threats they are intended to address in an effort to ensure a diversified and balanced approach to the implementation of recovery actions whereby funding and effort can be applied at the appropriate level for each recovery element. The recovery elements include: (1) Nonnative and Sportfish Management, (2) Habitat Development and Maintenance, (3) Water Management and Protection to Benefit June Sucker, (4) Genetic Integrity and Augmentation, (5) Research, Monitoring and Data Management, and (6) Information and Education.

<u>Nonnative and Sportfish Management</u>: Introductions of nonnative fish species into Utah Lake, which began in the late 1800's, has resulted in a change of the lake's fish community. Up to thirteen fish species naturally occurred in Utah Lake. Of these, only June sucker and Utah sucker (*Catastomus ardens*) are present today, but in extremely low numbers. At least twenty-four nonnative fish species have been introduced into Utah Lake and several of these have become established as self-sustaining populations. Those which have been particularly successful include common carp (*Cyprinus carpio*), white bass (*Morone chrysops*), black bullhead (*Ameiurus melas*), channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*), and walleye (*Stizostedion vitreum*). The establishment of populations of nonnative fishes in Utah Lake has contributed to the demise of native fish species and to the endangered status of June sucker, likely through predation and competitive interactions. Nonnative fish control to benefit June sucker is a significant part of the recovery effort. The approach of the JSRIP is to conduct feasibility analyses and make recommendations; implement pilot projects to monitor, evaluate, and refine recommendations; implement the recommended action on Utah Lake and tributaries; and monitor and evaluate the effectiveness of selected actions.

To date, the JSRIP has funded and completed an analysis investigating the feasibility of controlling nonnative fish to benefit June sucker in Utah Lake

(SWCA 2002). A review of 88 case studies showed that there was no apparent relationship between the size of a fish control project and its successfulness, and that efforts using combinations of treatments were most likely to be successful. Possible treatments for Utah Lake were evaluated and the highest ranking projects were developed further and recommended as pilot projects. The study suggests that although most species of nonnative fishes are not likely to be completely eliminated from the Utah Lake system, several species can be effectively reduced and controlled. Based on the feasibility study, the JSRIP has been investigating potential in-lake locations to establish as pilot study areas, and has funded additional research to guide future direction for nonnative fish control.

<u>Habitat Development and Maintenance</u>: Habitat within the Utah Lake ecosystem has been significantly altered since Utah Valley was settled in the mid-1850's. Human-induced habitat changes that have particularly affected June sucker include: channelization and diking of tributaries which reduced habitat complexity and productivity, altered thermal regimes, and changed flow dynamics; diversion structures on tributaries that limit access to potential spawning and nursery areas; and filling of tributary floodplain habitats and wetlands associated with tributaries and the wetlands along the lake shore which reduced habitat for early life stages of June sucker. These habitat alterations have contributed to the endangered status of the fish. Habitat enhancement projects to benefit June sucker are a significant part of the recovery effort. The approach of the JSRIP is to identify and prioritize areas of importance for habitat development; conduct feasibility analyses and make recommendations; implement pilot projects to monitor, evaluate, and refine recommendations; implement recommended actions and monitor and evaluate their effectiveness.

To date, the JSRIP has prioritized the lower Provo River historic floodplain and the lower Hobble Creek historic floodplain (first tributary south of the Provo River in Utah Lake) for habitat enhancement efforts. Feasibility studies on how to enhance the riverine/lacustrine interface and recreate historic deltaic function and habitats have been conducted for both tributaries (Bio-West 2002, Bio-West 2003). The JSRIP has received funds to acquire private land in these areas; however, acquisition is dependent on willing sellers and JSRIP partners are constrained to purchase prices at or below appraised value. Land is currently for sale in the Hobble Creek area but at this time private landowners in the lower Provo River target area are unwilling to sell at appraised value. The pace of on-the-ground habitat enhancement activities is moving slowly due to difficulties associated with acquisition of private land. The JSRIP is collaborating with the Utah Department of Natural Resources (a JSRIP partner) in negotiations with private landowners.

<u>Water Management and Protection to Benefit June sucker</u>: As a result of water development in the Utah Lake Basin, the hydrology of Utah Lake and its tributaries has been altered from the conditions in which the June sucker evolved.

Historic water management has contributed to the endangered status of June sucker by changing the natural hydrology of tributaries during spawning and nursery periods. A major challenge for the JSRIP is to manage and protect water resources necessary to provide sufficient habitat for June sucker recovery while maintaining and developing water for human use. JSRIP participants recognize and agree that all water operations are subject to existing water rights, judgements and decrees, and existing contractual obligations.

The June Sucker Flow Workgroup, a sub-committee of the JSRIP Technical Committee, has been effective at developing and implementing spawning and nursery flow recommendations in the Provo River. Program Participants recognize that the Recovery Plan (U.S. fish and Wildlife Service 1999) identifies areas other than the Provo River that may require special water management to benefit June sucker. For instance, the interim criteria for delisting June sucker include the establishment of an additional self-sustaining spawning run in a location other than the Provo River. Based on a review of tributaries to Utah Lake, the JSRIP is moving towards establishing an additional spawning run in Hobble Creek, a tributary stream south of the Provo River.

Flow recommendations include justification regarding June sucker recovery along with anticipated biological response. The Administration Committee reviews and finalizes all flow recommendations. Water necessary to implement JSRIP activities is acquired in accordance with State of Utah Water Rights Law.

To date, 4,700 acre feet of water has been permanently acquired for June sucker recovery purposes. Additional water has been obtained on a temporary basis. Several mechanisms have been employed to acquire this water including: direct purchase and applying a portion of water saved through conservation and efficiency projects to the June sucker recovery effort. Under the proposed action for the Utah Lake System – the final component of the CUP Bonneville Unit currently undergoing National Environmental Policy Act review – a permanent block of water (12,165 acre feet) targeted for June sucker recovery purposes in the lower Provo River has been identified. Additional water is targeted for delivery to lower Hobble Creek. This water, planned for delivery through newly constructed pipelines as part of the Utah Lake System, is a portion of the exchange water from Strawberry Reservoir to Utah Lake so that Provo River water can be stored in Jordanelle Reservoir (see Water Development and Operations section).

Genetic Integrity and Augmentation: Since the late 1980's, wild June sucker have been captured from the Provo River spawning run and artificially spawned. The thrust of this effort has been to maximize the number of paired crosses (single male x single female) with the goal to develop brood stock which represents, to the maximum extent possible, the genetic composition of the wild population. This is an ongoing effort with the target of at least twenty-five paired crosses.

Progeny from the artificial spawning program have been maintained in captivity in a hatchery and in several reservoirs or ponds. A warm water culture facility which prioritized the culture of June sucker for large-scale stocking into Utah Lake is undergoing the NEPA process (reference CUP Hatchery EIS). In the meantime, interim facilities are being used to hold brood stock and conduct research necessary to answer key culture and production questions. Moderate-scale production of June sucker at interim facilities will provide fish to be used to answer important stocking questions prior to implementation of large-scale stocking efforts.

An important part of this recovery element has been to synthesize the existing information into a genetic management plan designed to guide spawning operations, production, augmentation, and refuge development. This plan has undergone several revisions and is now considered a working document by the JSRIP. As new information becomes available, the plan will be updated accordingly.

Activities that have occurred to date include securing a refuge population in Red Butte Reservoir, approximately one mile east of Salt Lake City. June sucker in Red Butte Reservoir have spawned and successfully recruited to the population since 1995. It was only recently, though, that ownership of the reservoir was secured by the District, a partner to the JSRIP. Red Butte Reservoir and Camp Creek Reservoir – a privately owned reservoir in northwest Utah – serve as refuge locations for June sucker. The intent of refuge populations is to provide security in case a catastrophic event eliminated the population in Utah Lake; however, refuge populations also provide unique opportunities to conduct research in a protected setting and thereby gain valuable information to guide recovery decisions in Utah Lake. In addition, surplus fish from refuge populations have been collected and stocked into Utah Lake and have returned to the spawning run.

Captive brood stock are being held at Fisheries Experiment Station, a research facility operated by Utah Division of Wildlife Resources in Logan, Utah. Captive brood stock are necessary to provide for future stocking efforts to augment the Utah Lake wild population. Brood stock are managed under conservation genetic guidelines to ensure that stocked fish represent to the extent possible the genetic diversity of the wild population. To date, over 7,000 June sucker have been stocked back into Utah Lake.

<u>Research Monitoring and Data Management</u>: As with most sensitive species, little information on the basic biology and habitat needs of June sucker was gathered prior to its endangered status. Once listed, limited numbers of individuals in the remaining wild population existing in altered environmental conditions, made assessment of biological needs difficult. Prior to any on the ground actions, research is necessary to provide insight into the life history and habitat requirements of June sucker and its interactions with other species.

Information gained from applied research projects is used to guide recovery activities.

Data produced from research and monitoring efforts is also used in determining the success of the Program. Standard monitoring protocols have been drafted and are being implemented for various life stages of June sucker in Utah Lake, the Provo River and other tributaries. These data will provide trend information on population status and recruitment, habitat development, response to recovery actions, etc. Each recovery action conducted under the Program is monitored to assess its effectiveness.

Information and Education: A portion of the local public perceives Utah Lake of little value, economically or ecologically. Furthermore, local public attitudes towards endangered species, in general, are of low regard, particularly if there is the perception of potential conflict with public interests (ie. recreational angling, boating, water sports, etc.). Interpretation and education highlighting the value of the Utah Lake ecosystem and the June sucker and associated recovery efforts is an important and challenging part of the JSRIP.

The JSRIP has been very active in this recovery element. A local media relations firm was hired to develop and assist in the implementation of a public outreach and media relations plan. With their assistance the JSRIP published a book entitled Utah Lake: Legacy (Carter 2003) which highlights the value the Utah Lake ecosystem and its native fish community have had in local history. The book has been distributed to local elected officials, public libraries and educational institutions, and is offered for sale to the general public at local book stores. A documentary video highlighting the Utah lake ecosystem and the June sucker is currently being made that will be aired on local television and study guides for local schools are being developed. Prior to implementing the JSRIP and the public outreach and media relations plan, media coverage relating to the June sucker was predominantly negative and unsupportive. Since implementation of the plan; however, media coverage has been positive and supportive of JSRIP efforts.

SUMMARY

When the June sucker was listed as an endangered species, the population was estimated to be less than 1000 individuals. As evidenced by the following quote, early efforts were geared toward saving a viable population and avoiding extinction:

> "June suckers are precariously near to extinction. They remain only as a rapidly shrinking and aging remnant population, without recent successful reproduction. This demographic observation, combined with the

> overwhelming dominance of non-native fishes in Utah Lake and current water-management practices, may preclude their survival in nature . . . The June sucker population may have declined so low that extraordinary efforts will be required to avert extinction (Scoppettone and Vinyard 1991)"

With limited funding and lack of coordination among management agencies, early efforts to avoid extinction, although successful, were extremely difficult and confrontational. Today, most believe the threat of extinction has passed and the June Sucker Recovery Implementation Program provides the mechanism for funding and implementing actions in a coordinated and collaborative manner that are geared toward the actual recovery of the species.

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REMEDIATION OF SELENIUM CONTAMINATION AT THE STEWART LAKE WATERFOWL MANAGEMENT AREA IN NORTHEASTERN UTAH

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ABSTRACT

The Jensen Unit of the Central Utah Project was designed and constructed to provide supplemental water for agriculture and municipal and industrial uses, and provide drainage of saturated soils. During 1981-1998, drainwater from this federal irrigation project was delivered to Stewart Lake Waterfowl Management Area (Stewart Lake). Unknown at the time, the drainwater contained high concentrations of selenium from leaching through the Mancos shale-derived soils being irrigated, which contaminated the water, biota, and bottom sediment of Stewart Lake. Due to adverse affects to endangered fish, the Jensen Unit has been under a jeopardy opinion and formal section 7 consultation with the U. S. Fish & Wildlife Service under the Endangered Species Act. This formal consultation resulted in an incidental take statement with reasonable and prudent measures and associated terms and conditions, which included requirements to remediate Stewart Lake. Planning for remediation was initiated in 1992 by a National Irrigation Water Quality Program - Interagency Core Team (U.S. Geological Survey, U. S. Fish & Wildlife Service, Utah Division of Wildlife Resources, and the U.S. Bureau of Reclamation). Nearly 100 remedial management options were evaluated and the best were combined into six alternatives. Implementation of the Proposed Action started in 1997, but because of the uncertainty of its effectiveness, the plan was implemented in phases, with monitoring and evaluation at each decision point to maximize success (Adaptive Management). Definitive progress has been made in removing selenium from Stewart Lake and in reducing exposure of selenium to fish and wildlife; but additional removal of selenium from contaminated bottom sediments, or changing operating criteria, is necessary to eliminate remaining impacts to endangered fish and migratory waterfowl.

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INTRODUCTION

Background

Stewart Lake Waterfowl Management Area is located in northeastern Utah adjacent to the Green River, about 12 miles southeast of the city of Vernal, Utah. This marsh covers 696 acres and can be characterized as a wetland, with a water table within 12 to 36 inches of the land surface. About 430 acres are enclosed by an earthen dike and consist of 285 acres of surface water (including 110 acres of open water and 175 acres of emergent vegetation) and 145 acres of salt grass (see Figure 1. The other areas contain multiple vegetation types, including grasses, willows, cottonwoods, and salt cedar. Stewart Lake is owned and managed by the Utah Division of Wildlife Resources, specifically for waterfowl and other migratory birds. However, both endangered Colorado pikeminnow and razorback suckers have been observed there.

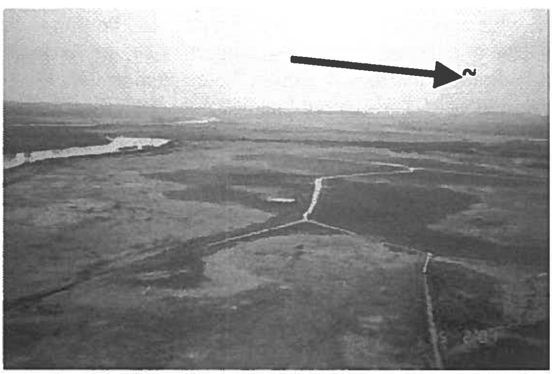

Figure 1. Stewart Lake Waterfowl Management Area (looking SW)

Jensen Unit area land has been irrigated through water right allocations for more than 100 years. The Jensen Unit of the Central Utah Project was designed and constructed by the U.S. Bureau of Reclamation (Reclamation) to provide supplemental water for agriculture and municipal and industrial uses, and provide drainage of saturated (waterlogged) soils. The project provides about 4,600 acre-feet of mostly supplemental water for 4,000 acres of agricultural lands, or about 25 percent of the total irrigation water supply. Five subsurface groundwater drains were constructed (1974 to 1981) to service about 700 acres of drainage-deficient lowlands near the northern edge of Stewart Lake. The drains are 8 to 10 feet beneath the agricultural land surface and spaced 1,390 to 6,670 feet apart.

The Jensen Unit, to comply with the National Environmental Policy Act (NEPA), was required to provide a water supply to Stewart Lake to replace the historical water supply from Ashley Creek that had been impacted by completion of the earlier (1960) Vernal Unit of the Central Utah Project. Water from the Jensen drains was tested in the early 1980s and appeared to be a suitable quality water supply for Stewart Lake. During 1981-1998, drainwater from Jensen Unit was delivered to Stewart Lake. Unknown at the time, the drainwater contained high concentrations of selenium derived from irrigation water leaching through the Mancos shale-derived soils which are high in selenium. The drainwater was removed and replaced with a clean water supply in 1998.

The current study is part of the Department of the Interior's (DOI) National Irrigation Water Quality Program (NIWQP) which identifies and remediates irrigation-induced water quality problems in the Western United States as a result of DOI projects.

The Problem: Pre-Project Contamination Levels

The Jensen Unit irrigation drains have median dissolved selenium concentrations ranging from 30 to 77 μg/L (ppb), and flow-weighted average concentrations ranging from 9 to 46 μg/L. The combined annual average flow is about 1,700 acre-feet and ranges from about 1,500 to 2,000 acre-feet. Most of the biologically available selenium in Stewart Lake comes from the input of the Jensen irrigation drains. However, the specific amount of selenium contributed by Jensen Unit drainage is not known.

The selenium concentration of water leaving Stewart Lake before any remediation was initiated ranged from 1 to 12 μg/L and averaged about 5 μg/L. Concentrations of total selenium in bottom-sediment samples near the discharge points of the drains were as high as 720 mg/kg (ppm) dry weight, and most of the upper sediments in the northern portion of Stewart Lake exceeded the target background "clean" level of 4 ppm.

Elevated concentrations of selenium in water and bottom sediment contributed to high concentrations appearing in fish and waterfow and this, in turn, contributed to decreased nesting success by water birds (Stephens et al. 1992). Selenium toxicity threshold levels are: >2 μg/L for water, >4 mg/kg dw for sediment, >3 mg/kg dw for diet, >6 mg/kg dw for waterbird eggs, and >4 mg/kg dw for whole-body fish (DOI 1998).

The Goal

The ultimate purpose of this project is to protect and restore, to the extent possible, fish and wildlife resources in the Stewart Lake Waterfowl Management Area, the outlet channel, and in the mixing zone in the Green River. The need is to reduce selenium concentrations in Stewart Lake to safe levels to restore the biological productivity and eliminate documented impacts to endangered fish and migratory waterfowl which have resulted from irrigation drainage from the Jensen Unit (DOI 1998).

PLANNING FOR REMEDIATION

Planning for remediation has been conducted at Stewart Lake by a NIWQP Interagency Core Team (U.S. Geological Survey, U. S. Fish & Wildlife Service, Utah Division of Wildlife Resources, and Reclamation) since 1992. Nearly 100 remedial management options were evaluated and the best were combined into six alternatives. The proposed action includes removing the contaminated irrigation drain water discharging from Jensen Unit underground irrigation drains and replacing the water with an alternate clean water supply, and cleaning up the contaminated bottom sediment. A Final Environmental Assessment and Finding of No Significant Impact were completed in September 1997, and construction for remediation started that same year.

Because the effectiveness of any proposed action was uncertain, the current action is being implemented in phases, with monitoring and evaluation at each decision point to maximize success. This approach is known as "Adaptive Management."

REMEDIATION IMPLEMENTATION

The Proposed Action consists of two phases as discussed below.

Phase One Activities

Phase one activities started in May 1997 and were essentially completed in June 1998. Activities included:

1. Excavate a new inlet channel - (completed May 1997) - A new inlet channel was excavated to connect Stewart Lake at the upper end to the Green River to allow flow-through flushing and circulation. This was a pilot study to see if flow-through flushing of the lake with clean water could effectively reduce selenium in lake sediments and in food for fish and waterfowl. Water from the Green River in May has very low selenium concentrations, usually less than 1 ppb. During the 1997 runoff season, approximately 35,000 acre-feet of high quality Green River water flowed through the Lake over a period of six weeks.

2. Excavate channels to completely drain Stewart Lake - (completed Oct 1997) - Complete draining of Stewart Lake was made possible by lowering the outlet from Stewart Lake to the Green River by about two feet and excavating drainage channels. Draining the lake could potentially reduce selenium in sediment by enhancing oxidation. The inability to completely drain Stewart Lake required using an amphibious hydraulic excavator to dig drainage channels through the lake. The main drainage channel is more than 5,000 feet long, 18 feet wide, and 3

feet deep. The Lake was essentially dry three weeks after the drainage channels were completed.

3. Extend the Jensen Unit agricultural drains to discharge directly into the Green River - Extending the existing drains to the Green River eliminated the major source of selenium to Stewart Lake, and is a very critical element in its recovery. Irrigation Drains J1 and J1A were combined and extended through 1,400 feet of 18-inch pipe to the Green River during November 1997. The 10,000 foot 24-inch pipe extension of combined Drains J2, J3, and J4 around the west end of Stewart Lake was completed in June 1998.

4. Monitor water, sediment, and biota to evaluate the effectiveness of activities - Monitoring and evaluation are an integral part of each step to determine appropriate further steps.

During the 1997 flooding episode, limited monitoring indicated about 210 pounds (95 kg) of selenium entered Stewart Lake (mostly from the drains), and about 360 pounds (163 kg) were discharged, or a net loss of 150 pounds (68 kg). However, selenium levels in the Green River downstream never exceeded 1 µg/L.

Bottom sediment from Stewart Lake was sampled in 1995 and 1997 after the flooding. The 1997 flooding may have reduced the selenium concentration of the near-surface bottom sediment in Stewart Lake by 5 to 25%.

About 5 acre-feet of clean sediment was deposited in Stewart Lake in 1997 by diverting 35,000 acre feet of Green River through the inlet channel. Continued sediment deposition from Green River inflows could cause operational problems.

Phase Two Activities

Phase two activities, started in 1998 and to continue over a 5- to 8-year period, include the following:

- Continue flushing and drying Stewart Lake for several years.
- Construct Inlet Control Structure - Completed May 1999.
- Construct new Outlet Control Structure - Completed May 1999.
- Agreement to Deliver Water Supply - Completed June 2000.
- Design and Construct Water Supply - Completed October 2002.
- Extend Drain J1-J1A extension below Inlet Structure – Completed November 2001.
- Conduct tilling, lime treatment, and fall flooding tests to remove selenium from sediments (see Figure 2).
- Design, complete NEPA requirements, and construct a drain water seepage collector system along the north edge of Stewart Lake. Recent

studies by DOI have determined that the remaining natural seeps and springs along the north edge of Stewart Lake contribute about ten percent as much selenium as the Jensen Unit Drains, which were removed from the Lake by 1998. – Completed May 2004.

- Evaluate additional methods to reduce selenium in sediments, if needed.
- Continue monitoring to determine the effectiveness of the remediation and adaptive management activities.

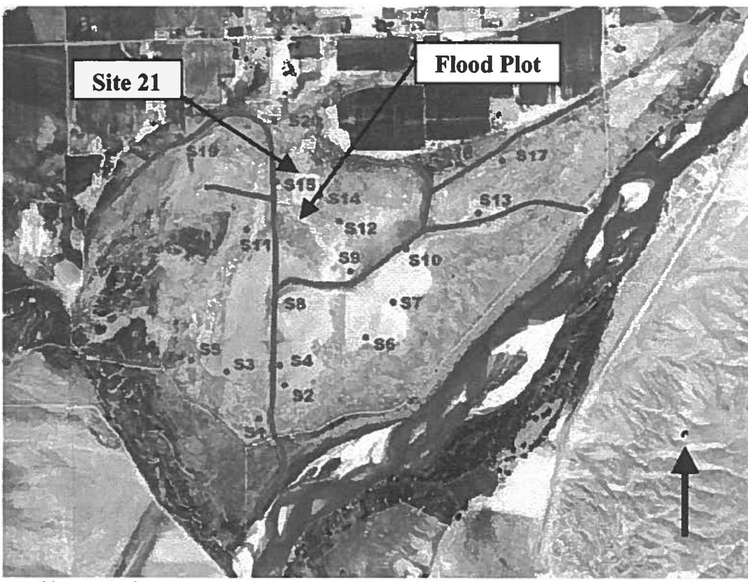

Figure 2. Stewart Lake drained, showing drainage channels (dark lines), numbered sampling sites and test plots.

DISCUSSION OF IMPACTS: WATER QUALITY, SEDIMENT, BIOTA

Water Quality

Constructed irrigation return flow drains have previously discharged large amounts of selenium into Stewart Lake. Between 1993 and 2001, the average cumulative daily selenium load carried by the irrigation drains was 0.2 kg/d, or 73 kg/yr. This selenium load was added directly to the Green River starting in 1997-1998. Selenium loads in the Green River near Jensen, Utah gage site (upstream of discharge from constructed drains) ranged from about 9 to 64 kg/d (Chafin et al. 2001).

After completion of the seepage collection system, approximately 0.004 to 0.024 kg/d of additional selenium loading will be diverted from Stewart Lake to the Green River. This loading value is based on three years of seep monitoring data conducted from 2000 to 2002.

Six wells within and adjacent to Stewart Lake have been monitored since 1996, and selenium concentrations in the shallow ground water beneath the Lake have remained low, usually below 10 µg/L (see Figure 3). Results from a flooding experiment conducted in 2002 indicate that selenium concentrations in the shallow ground water can exceed 800 µg/L for short time periods during infiltration events. The increased selenium concentration in the ground water quickly returns to baseline conditions, probably the result of the chemically reducing conditions in the shallow ground water and the conversion of selenate (Se+6) to lower valence oxidation states which are removed from the aqueous phase through adsorption (selenite, Se+4) or precipitation reactions (elemental Se, Se0, and selinide, Se-2).

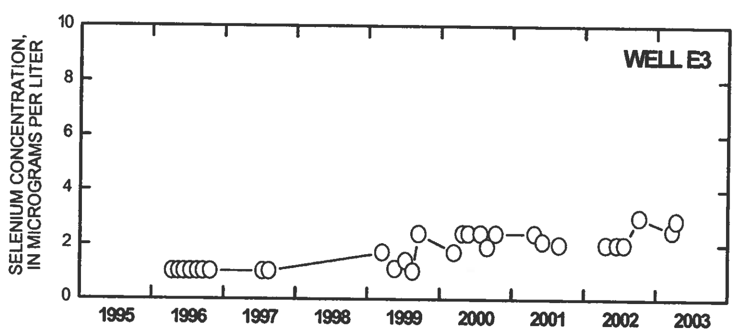

Figure 3. Changes in selenium concentration in shallow ground water beneath Stewart Lake during 1996-2003.

Sediments

Since 1997, Stewart Lake has been seasonally drained to allow for oxidation of reduced forms of selenium prior to the spring flood of the Green River, which usually is large enough to flow through Stewart Lake. The draining and flooding is designed to remove oxidized selenium from the sediments and carry it to the Green River. Figure 4 shows a plot of the annual post-flood geometric mean total selenium in the Stewart Lake sediments since 1995 (Yahnke 2004).

The overall annual mean total selenium data indicate a decrease to <10 ppm in 1997 from about 13 ppm in 1995. There was a subsequent increase in 1998. The overall mean selenium concentration has remained at 15 ± 2 ppm since then.

Although the overall increase amounted to about 5 ppm, there was an increase of about 20 ppm in the sediments in the north end of the lake (see Figure 4).

Figure 4 also shows plots of the annual geometric means of two subsets of the total selenium data. The subsets consist of post-flood or autumn samples from sites in the north and south ends of Stewart Lake. As can be seen from Figure 4, the total selenium was rather evenly distributed throughout Stewart Lake in 1995,

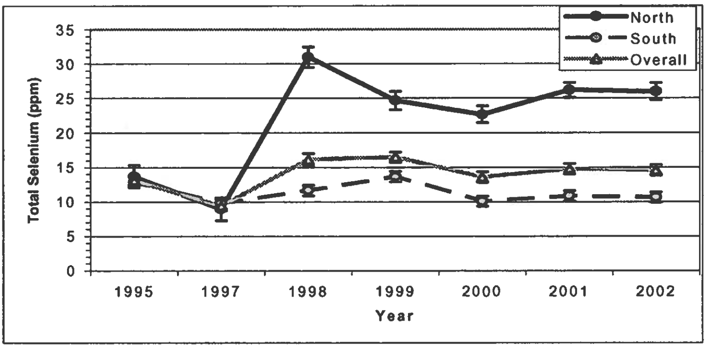

Figure 4. Mean annual total selenium concentrations in Stewart Lake surface (0-6 inch) sediments

when the lake was permanently flooded, and in 1997, when the spring flood entered from both the Green River and Ashley Creek and spread throughout the lake. Most of the increase during 1998 occurred in the north end of Stewart Lake. In 1999, there was a 5 ppm decrease in the sediments at sites in the north end of the lake. That decrease coincided with an increase of about 2 ppm in the south end of the lake. The net effect was no change in the overall total selenium concentration in the sediments from 1998 to 1999. Since 1999, there has been essentially no change in total selenium in the surface sediments of Stewart Lake. In comparison to the 1995 pre-Project total selenium levels, the overall selenium concentrations in the surface sediments in the most recent samples show no change. In the subsets, there has been an increase in the selenium in the sediments in the north end of the lake and a decrease in the selenium in the sediments in the south end of the lake.

Fish, Birds, Biota

Sampling in the late 1980's and early 1990's confirmed elevated selenium concentrations in biota at Stewart Lake. The primary concerns of the U.S. Fish and Wildlife Service (USFWS) were reproductive impairment in endangered fish and migratory waterfowl. Limited sampling of razorback muscle tissue has shown selenium concentrations as high as 54.1 ppm dry weight (dw) (Waddell and May 1995), which is 13 times higher than the DOI recommended effect threshold of 4 ppm dw (DOI 1998). The possibility for reproductive impairment in razorback suckers clearly existed. Because reproductive impairment would jeopardize the continued existence of a listed species, immediate action to eliminate or reduce this threat was required. In addition, reproductive impairment in migratory birds due to selenium was also documented. These species are protected by the Endangered Species Act and the Migratory Bird Treaty Act, respectively.

Numerous biological samples were collected at Stewart Lake from 1988 to 1992. Geometric mean selenium concentrations in eggs from black-crowned night herons ($n = 6$) and western grebes ($n = 7$) were 18.3 and 24.6 ppm dw, respectively. Whole-body selenium concentrations in common carp were also elevated, but showed spatial variation relative to position in the lake: geometric mean selenium concentrations at the north shore were 47.9 ppm dw ($n = 8$), but were only 29.3 ppm dw ($n = 13$) at the south side of the lake. The general condition of Stewart Lake was summarized by Stephens et al. (1992):

> Stewart Lake supported a generally depauperate biota. Nesting success by waterbirds was poor, there were few insects, and selenium concentrations in tissue were large. Mean selenium concentrations in most whole-body fish exceeded the value of 12 µg/g associated with reproductive impairment.... Several deformed waterbirds (redhead and cinnamon teal) were found at Stewart Lake WMA. (p.155)

Calculation of the selenium loading to Stewart Lake suggested that approximately 152 pounds of selenium were annually incorporated into sediment, and biota (Stephens et al. 1992, p.154)

Since 1995, geometric mean selenium concentrations in Green River carp (between Dinosaur National Monument and Ouray National Wildlife Refuge) have declined by nearly 43%, while at the site adjacent to Stewart Lake, geometric mean selenium concentrations have declined by about 53%. Similar declines were also observed within Stewart Lake (for analysis, fish were pooled into pre- [1995-1997] and post-remediation [1998-2001] groups). At the North Overlook and near the Outlet, geometric mean selenium concentrations have declined by approximately 28% and 39%, respectively. Bird eggs were collected intermittently, but show no clear trend.

CONCLUSIONS

Selenium contaminated drainwater has likely contributed to the decline of endangered fish in the Green River. Toxicity studies have shown negative reproductive effects at concentrations below those observed in Green River fish. Other factors adversely affecting these fish may include river management, flow depletion, water and power marketing, channelization and loss of flood plain habitats, competition from nonnative fishes, and other ecosystem changes.

Reductions in selenium concentrations in biota found in Stewart Lake and the Green River indicate that the situation at Stewart Lake has improved over that found in the late 1980's and early 1990's; however, this change may be due to current seasonal water management which limits exposure, rather than a noticeable decline in available selenium in sediments.

Additional monitoring is needed after the seeps are removed to document the progress or success of the cleanup, and to document that the Stewart Lake is no longer a hazard to migratory birds or endangered fish.

Definitive progress has been made in removing selenium from Stewart Lake; however, residual elevated selenium concentrations still exist. Therefore, additional selenium removal and/or a long-term Monitoring and Management Plan recommending operating criteria needs to be developed to assist the Utah Division of Wildlife Resources in managing Stewart Lake to minimize effects of selenium to endangered fish and migratory waterfowl.

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POTENTIAL WATER AND ENERGY CONSERVATION AND IMPROVED FLEXIBILITY FOR WATER USERS IN THE OASIS AREA OF THE COACHELLA VALLEY WATER DISTRICT, CALIFORNIA

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ABSTRACT

The Oasis Area of the Coachella Valley Water District (CVWD) consists of approximately 12,000 acres of farmland with 220 water users. Approximately 50,000 acre-feet of Colorado River water are delivered to the area annually. Water is conveyed from the Coachella Canal across the valley in a single irrigation lateral. Once in the Oasis Area, the water enters a small storage tower where it is distributed to 4 sublaterals. All pumps operate off of 2 of the sublaterals which lift 10,000 acre-feet of water annually to 2,000 acres of land. Approximately 265 acre-feet of regulatory discharge and operational spillage occur annually from regulatory meters at the ends of the laterals or from the tower overflow.

A study was conducted by JMLord, Inc. to determine the feasibility of improvements to the Oasis Area distribution system of CVWD. Recommended improvements were selected based on their ability to provide water and energy conservation and to increase flexibility in water ordering by, and delivery to, water users within operational limits.

The basis of the Feasibility study of the Oasis system provides a discussion and recommendation for the following:

1. Improving efficiencies of the seven (7) booster pump stations;
2. Replacing/upgrading water distribution controls at each of the seven (7) booster pump stations to facilitate improved leak detection and to increase flexibility in water ordering by, and delivery to, water users within operational limits;
3. Constructing an operating spill and regulatory recovery systems, which includes associated collection, conveyance and pumping facilities; and
4. Automating the distribution system.

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The overall benefit cost ratio of recommended improvements was 1.90 with an annualized cost of $78,743 and an annual benefit of $149,610. Recommended improvements include upgrading six of seven pump stations with variable frequency drives and SCADA controls, connecting regulatory meters to existing farm reservoirs and installation of flow meters, and construction of a regulating reservoir with a high water elevation equal to that of the tower.

PREAMBLE

This study was funded under the California Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection Act, Agricultural Water Conservation Program, the State of California Department of Water Resources (DWR), Contract No. F63103.

The purpose of the study was to determine the feasibility of improvements to the Oasis Area distribution system of the Coachella Valley Water District (CVWD). Recommended improvements were selected based on their ability to provide water and energy conservation and to increase flexibility in water ordering by, and delivery to, water users within operational limits.

BACKGROUND

Pumping Systems

Pump stations, called O-pumps, in the Oasis area are dual parallel or single pump systems. These pump systems lift 10,000 acre-feet of water annually to 2000 acres of agriculture land. The annual pumping cost for the O-Pumps is estimated to be $130,000. Thus the average pumping cost per acre-foot of water is around $13.00. The daily demand at each O-Pump station ranges from 0 to 15 cubic feet per second (cfs) depending on the particular pump station and daily water orders.

The pumping cost analysis indicated that a significant amount of energy is consumed annually due to losses in manual control valves downstream of the pumping systems (estimated at $61,710 in energy loss). Control valves are "throttled" to match pump flows. Energy consumption may be minimized by matching the head produced by the pumps to system requirements over the range of demand flows and by maximizing overall pumping plant efficiency.

Alternative considerations include replacement of the current pump systems with pump systems matched to the delivery system head/demand profiles (thereby minimizing throttling). Alternatives considered are:

1. Two pumps of the same size
2. Two pumps, one small for low volumes, one large for high volumes
3. Replace one of the pumps with a Variable Frequency Drive (VFD) pump

Tower System

The Oasis Tower is an unsealed cylindrical tank, approximately 50 feet in height. The water surface elevation in the tower is controlled by adjusting the radial and check gates at the Coachella Canal and by adjusting the distribution gates at the base. The water surface elevation in the tower is regulated over a range of approximately 3 feet. In order to prevent spillage from the tower, the maximum water level is not exceeded. The minimum water surface elevation is maintained to reduce the risk of the O-1, O-3, and O-4 pumps losing suction. Typically, the water surface elevation is maintained at 0.5 – 1.5 feet below the maximum water level. The wasteway from the tower was determined to have a capacity of 30 cfs. Excess flows to the tower above 30 cfs are expected to result in overtopping of the tower.

The Oasis Tower acts as the distribution point for water deliveries to the Oasis Distribution System. The daily flow to the tower is controlled at the Coachella Canal. Adjustments at the canal require 15 minutes before the impact reaches the tower. Storage capacity of the tower is virtually non-existent.

Due to the amount of time required for flow adjustments at the canal to impact the Oasis Distribution System, it would be desirable for the Oasis Tower to provide some storage to account for differences in the amount of water supplied by the canal and the amount distributed through the Oasis system at any given time. Of particular concern is that starting/stopping the O-Pumps simultaneously could result in significant drawdown or discharge within the tower. In such an event, the available storage of the tower fails to compensate for possible excess supply from the canal. Excess water, which overflows the tower, could cause the tower to collapse due to erosion at the base and/or flooding of nearby areas. The analysis presented here provides insight into the effect of starting/stopping pumps simultaneously on the water level in the tower.

Regulatory Discharge Systems

There are six regulatory flow meters throughout the Oasis system. These meters are used solely for regulatory discharge, they are not capable of providing normal canal water service to growers. System upgrades to allow for the capture and/or elimination of regulatory discharge are investigated.

METHODS

Pump Systems Analysis

The pump systems analysis was performed to find ways of minimizing electrical consumption for each O-Pump station. Replacement pumps or VFDs were selected that match the system head requirements and demand profile as closely as possible. Pump line performance curves and operating strategies that minimize electrical consumption were generated for several alternatives.

Pump performance curves relating flow to head for each O-Pump station were developed from multi-point pump test. For pump stations with two pumps operating in parallel, a pump performance curve relating head to flow for the two pumps operating simultaneously was also developed. A sample plot showing two pump performance curves and the curve resulting from operating both pumps in parallel is shown in Figure 1.

Note that the curve relating overall pumping plant efficiency (OPPE) to flow is a combined curve representing the OPPE over the full range of flows that can be provided by each pump. In the first portion of the curve, the small pump (Pump #1) is run. In the middle region, the large pump (Pump #2) is run. In the third region, both pumps are run to satisfy flow and head requirements.

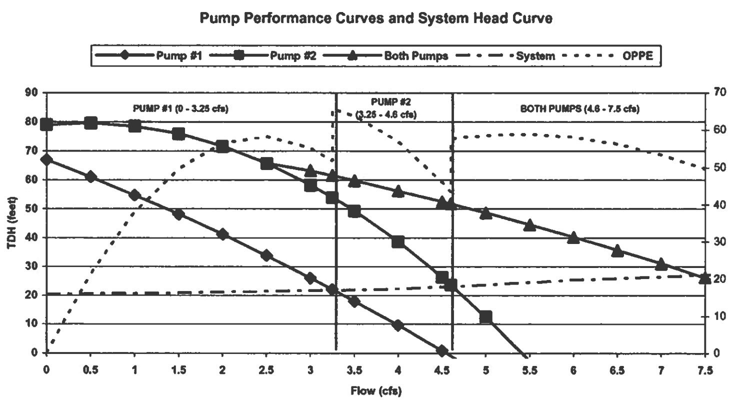

Figure 1. Sample Pump Performance Curves

The system head curve in addition to the pump performance curves is also shown in Figure 1. The system head curve provides the head required to satisfy the lift requirements and pressure losses of the system at a given flow. The three regions of operation are developed by finding the flow at which the head produced by the pump is equal to the system head requirements. A system head curve was generated for each pump station using the Hydraulic Model of the Oasis Area Distribution System.

Replacement pumps were selected to provide at least 120% of the required system head for their range of operation. The 20% factor of safety should account for pump wear, uncertainty of the system head requirements, and uncertainty of the maximum demand at each pump station.

Pump selection design points were selected to ensure adequate delivery capacity and to minimize pumping costs. Historic demand distributions and system head requirements define the minimum requirements of the pumps. Best efficiency or "design" points were selected based on the average flow within each pump's operating range.

The average rate for all pumping plants and the Oasis Tower was $0.085 per kilowatt-hour (based on power records for year 2000). Comparing the expected energy consumption of each alternate to current consumption provided an estimate of savings expected.

Costs estimates to implement the Replace Pumps or VFD additions were provided based on the design points determined for replacement pumps. Additional costs include the addition of a pressure sensor, a flow sensor and SCADA Programming.

Changes in annual operation and maintenance requirements were estimated for the install VFD alternative only. Because a VFD requires cooling, energy used by the air conditioning unit was added as an increase to the annual energy cost.

The VFD is equipped with a PLC to control the speed of the pump and motor electronically. The difference in operation is that no manual throttling is required by the operator to achieve the desired head. This decreases the time at the pump station, which translates to reduced vehicle wear and gas use. Since the flow can be controlled remotely, it also reduces personnel hours.

The total capital cost of the improvement was divided by ten to determine the amortized cost of the improvement. For each improvement alternative, the annual implementation cost was calculated by adding the amortized cost of the improvement to the increased annual maintenance cost.

Benefit-cost ratios of each alternative are calculated by dividing the projected annual pumping cost savings by the annualized implementation cost of the improvement. Alternatives with benefits exceeding costs (benefit-cost ratio > 1) were considered viable.

Tower Analysis

Minimization of regulatory discharge is the primary goal of changes to the tower system. The cost of water was estimated to be $60 per ac-ft. The annual regulatory waste from the tower operations is 15 ac-ft. Therefore, the expected annual watersavings is $60 per ac-ft x 15 ac-ft per year, or $900.

The Oasis Tower was modeled by examining USBR drawings of the structure, which specify tower size and shape. The drawings also provide maximum, normal, and minimum water surface elevations. District employees familiar with the Oasis system have provided further insight into the operation of the tower, the operation of the 97.1 lateral and canal gates, and the effect of tower water levels on the operation of the O-Pumps.

The daily flow through the Oasis Tower to the distribution system ranges from 0 to 135 cfs, with an average flow of 65.4 cfs and a standard deviation 28.4 cfs. Approximately 50,000 acre-feet of water are delivered each year through the 97.1 lateral to the Oasis Distribution system.

The maximum expected flow to the O-Pumps was calculated from the average and standard deviations of the daily flow to the O-Pumps of the 97.1-7.1W lateral. The maximum flow was calculated as the average flow plus 3 standard deviations.

The relationship of the change in water level in the tower to the amount of time elapsed after the pumps start is provided in Equation 1.

$$dh/dt = [Q_{in}(t) - Q_{out}(t)] / A \qquad \text{[EQ 1]}$$

Where,

dh/dt = change in water surface elevation within the tower per unit time in units of feet per second.
$Q_{in}(t)$ = flow into tower at time, t, in units of cubic feet per second.
$Q_{out}(t)$ = flow out of tower at time, t, in units of cubic feet per second.
t = time elapsed relative to pumps starting in units of seconds.
A = cross-sectional area of tower in units of square feet.

Note that if $dh/dt > 0$, the tower will fill. If the water level reaches the maximum water surface elevation, the excess flow to the tower is diverted to the wasteway. Once the water begins to spill from the tower, it is assumed that the water surface elevation in the tower remains constant at the maximum value.

Assuming that the gravity-fed portion of the distribution will perform exactly the same regardless of the O-Pumps, the portion of the flow into the tower that supplies the gravity-fed portion of the system may be neglected. Thus, $Q_{in}(t)$ may be defined as the flow into the tower designated for the O-Pumps, and $Q_{out}(t)$ may be defined as the flow out of the tower to the O-Pumps.

Equation 2 was integrated to provide the water surface elevation in the tower as a function of time.

$$h(t) = 1/A\ [Q_{in}(t) - Q_{out}(t)]dt + h_0 \qquad h_{min} < h < h_{max} \qquad \text{[EQ 2]}$$

Where,

$h(t)$ = water surface elevation in tower at time, t, in units of feet.

h_0 = initial water surface elevation in tower at time, t, in units of feet.
h_{min} = minimum water surface elevation at which pumps lose suction in units of feet..
h_{max} = maximum water surface elevation at which tower begins to overflow, in units of feet.

When the water in the tower drops below the minimum water surface elevation, the O-Pumps of the 97.1-7.1W lateral are assumed to lose suction and stop pumping. Thus, Q_{out} drops to 0 cfs.

The flows into and out of the Oasis Tower were modeled as step functions, assuming that the pumps start pumping at full flow, and that the individual flows through each pump impact the tower at the same time. The increased supply from the canal reaches the tower as an instantaneous increase in flow.

In reality, changes in flow within the system occur more gradually. Pumps may be started at low flow and the flow gradually increased by opening control valves downstream of the pumps. Additional flow is not released from the canal all at once, rather it is gradually increased until the desired flow is supplied.

The time that increased flow from the canal reaches the tower is a function of the time at which the canal gates are operated and the time required for flow released from the canal to reach the tower. For purposes of this analysis, 15 minutes is used as the time it takes for increased flow from the canal to reach the tower.

Adding a reservoir with a high water elevation equal to the overflow tower elevation would reduce or eliminate spillage and risk of tower failure while preventing loss of service to water users. Further, the reservoir could be located to provide groundwater recharge as a secondary benefit. The water could percolate or be pumped back (or backflow by gravity) into the tower when needed. Adding a reservoir to the system would virtually eliminate the approximately 15 ac-ft of regulatory water that is currently lost annually.

A cost estimate to construct and install a reservoir system was provided based on the reservoir system operational characteristics. The amortized cost was estimated by assuming a useful life of 10 years. The total capital cost of the improvement was divided by ten to determine the amortized cost of the improvement.

Regulatory Meter Analysis

Avoidance of regulatory discharge is the primary goal of changes to the regulatory system. The cost of water was estimated to be \$60 per ac-ft. The annual regulatory waste through the regulatory meters is 300 ac-ft. Therefore, the expected annual savings is \$60 per ac-ft x 300 ac-ft per year, or \$18,000.

Existing farm reservoirs could be used to help store and utilize regulatory discharge water. This would be a win-win situation for both the grower and the District. The District would minimize regulatory discharge, save the initial cost and annual maintenance of a new reservoir, and save the cost and maintenance of a pump-back system. The grower would receive "excess" canal water periodically at no charge, which in turn would provide water savings to the District. The overall effect would be to effectively eliminate this small regulatory discharge. The analysis focused on identifying existing reservoirs to be used for each of the six regulatory meters.

A cost estimate to construct and install pipe stands with baffles was provided based on the pipe stand/baffle design. The amortized cost was estimated by assuming a useful life of 10 years for the upgrades. The total capital cost of the improvement was divided by ten to determine the amortized cost of the improvement. The regulatory meter sites require a flow sensor and a pipe stand with baffle.

RESULTS

Pump Systems

The Benefit-Cost results of the pump improvements are provided in Table 1. The alternative to install a VFD generally provided the greatest benefit-cost ratio. Based on the results, upgrades to 6 of the 7 pumps stations (O-1, O-3, O-4, O-5, O-6 and O-7) with Variable Frequency Drives and the associated sensor instruments and SCADA upgrades were recommended.

Tower System

The tower analysis showed that the time required for the tower to begin spilling into the wasteway is 2.59 seconds and the cumulative discharge from the tower is 24,000 ft^3 or .56 ac-ft. Therefore, for each event, approximately 0.56 ac-ft regulatory discharge can be expected due to lack of tower storage, indicating the need for additional tower storage.

Table 1. Benefit-Cost Ratios of Improvement Alternatives

Pump System	Alternative	Projected Savings	Annual Implementation Cost	Benefit-Cost Ratio
O-1	Replacement with Two Identical Pumps	$3,880	$3,240	1.20
O-1	Replacement with Two Different Pumps	$8,820	$2,960	2.98
O-1	Installation of VFD, Pump #2	$20,040	$3,650	5.49
O-2	Replacement with Two Identical Pumps	-$1440	$2,370	-0.61
O-2	Replacement with Two Different Pumps	-$300	$2,415	-0.12
O-2	Installation of VFD, Pump #2	$1,220	$2,680	.46
O-3	Replacement with Two Identical Pumps	$4,091	$3,150	1.30
O-3	Replacement with Two Different Pumps	$6,857	$3,045	2.25
O-3	Installation of VFD, Pump #1	$8,860	$3,650	2.43
O-4	Replacement with Two Identical Pumps	$3,240	$3,910	0.83
O-4	Replacement with Two Different Pumps	$12,780	$3,605	3.55
O-4	Installation of VFD, Pump #1	$18,940	$4,235	4.47
O-5	Replace Pump	-$4,740	$1,275	-3.72
O-5	Installation of VFD	$1,560	$1,500	1.04
O-6	Replace Pump	$3,770	$1,150	3.28
O-6	Installation of VFD	$9,000	$2,850	3.16
O-7	Replacement with Two Identical Pumps	$2,240	$2,200	1.02
O-7	Replacement with Two Different Pumps	$4,980	$2,180	2.28
O-7	Installation of VFD, Pump #1	$1,800	$1,320	1.36
O-7	Installation of VFD, Pump #2	$3,310	$1,700	1.95

Regulatory Meter

Farm reservoirs were identified near 5 of the regulatory meters. Using these results, of the 300 ac-ft total discharge, approximately 250 ac-ft of regulatory water could be eliminated.

Benefits and Savings

Benefits to be achieved include: (1) Increased level of service to water users, (2) Reduced wear and increased pump efficiency, (3) Reduction in vehicle wear and fuel use, (4) Reduction in labor costs, (5) Reduced stress on operational personnel, (6) Energy savings, (7) Water savings and (8) Costs may be recouped within 5 years.

Total annual savings for energy, water, equipment and labor due to the recommended changes are provided in Table 2. This table presents the total annual savings of $149,610.

Table 2. CVWD Annual Savings

Item	Energy	Water	Equipment	Labor	Total
O-1 Pumps	$20,040		$2,000	$10,000	$32,040
O-3 Pumps	$8,860		$2,000	$10,000	$20,860
O-4 Pumps	$18,940		$2,000	$10,000	$30,940
O-5 Pump	$1,560		$2,000	$10,000	$13,560
O-6 Pump	$9,000		$2,000	$10,000	$21,000
O-7 Pumps	$3,310		$2,000	$10,000	$15,310
Regulatory Meters		$15,000			$15,000
Tower		$900			$900
Total	$61,710	$15,900	$12,000	$60,000	$149,610

Annual Cost

Total costs for equipment and installation cost are summarized in Table 3. The total cost is $ 733,445.

Note that another cost that must be considered is the cost of project management and integration. This is estimated to be 7.5% of the total program costs. This includes the detailed in-house design, development of the RFP, integration, inspection, and project administration.

The annual amortized costs of the program are presented in Table 4. The total yearly cost is $ 78,743. Annual savings vs. annual amortized cost is shown in Table 5. The yearly net savings is $70,867.

Simple payback years then (calculated as the total equipment and installation costs divided by the total annual savings) is 4.9 years. The overall benefit-cost ration is 1.90. These results indicate that it is feasible to proceed with the recommended improvements.

Table 3. Total Equipment and Installation Cost

Item	VFD Equip & Install	Meter & Reservoir Install	Distributed SCADA Programs	Sensor Equip & Install	Project Cost (7.5%)	Total
O-1 Pumps	$27,500		$1,000	$13,100	$3,120	$44,720
O-3 Pumps	$27,500		$1,000	$13,100	$3,120	$44,720
O-4 Pumps	$33,350		$1,000	$13,100	$3,559	$51,009
O-5 Pump	$6,000		$1,000	$7,645	$1,098	$15,743
O-6 Pump	$19,500		$1,000	$13,100	$2,520	$36,120
O-7 Pumps	$8,000		$1,000	$7,645	$1,248	$17,893
Meters		$36,735			$2,755	$39,490
Tower		$450,000			$33,750	$483,750
Total	$121,850	$486,735	$6,000	$67,690	$51,170	$733,445

Table 4. Annual Amortized Cost

Item	Annualized EQ & Installation Cost	Additional Annual Maint/Ops Expenses	Annual Cost
O-1 Pumps	$4,472	$900	$5,372
O-3 Pumps	$4,472	$900	$5,372
O-4 Pumps	$5,100	$900	$6,000
O-5 Pump	$1,574	$900	$2,474
O-6 Pump	$3,612	$900	$4,512
O-7 Pumps	$1,789	$900	$2,689
Regulatory Meters	$3,949		$3,949
Tower	$48,375		$48,375
Total	$73,343	$5,400	$78,743

Table 5. Annual Benefit vs. Cost

Item	Annual Savings	Annual Cost	Difference	B-C Ratio
O-1 Pumps	$32,040	$5,372	$26,668	6.0
O-3 Pumps	$20,860	$5,372	$15,488	3.9
O-4 Pumps	$30,940	$6,000	$24,940	5.2
O-5 Pump	$13,560	$2,474	$11,086	5.5
O-6 Pump	$21,000	$4,512	$16,488	4.7
O-7 Pumps	$15,310	$2,689	$12,621	5.7
Regulatory Meters	$15,000	$3,949	$11,051	1.4
Tower	$900	$48,375	-$47,475	0.02
Total	$149,610	$78,743	$70,867	1.90

HYDROLOGIC ANALYSIS PROCESS FOR ENVIRONMENTAL IMPACT STUDIES
UTAH LAKE DRAINAGE BASIN WATER DELIVERY SYSTEM

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ABSTRACT

Concise, complete, and consistent surface water hydrologic results are essential to the accurate analysis of impacts in a water supply related environmental impact study. Likewise, a complete hydrologic analysis process is essential to the efficient development of usable hydrologic results. This paper summarizes a hydrologic analysis process that is general enough to be applicable to a wide-range of water supply development projects, yet complete enough to aid the hydrologist in developing and carrying-out a thorough and well organized study. The subject process includes six stages (background, baseline, issues, alternatives, analysis, and documentation) that were developed based on the completion of several large environmental studies, and refined in the completion of the Utah Lake Drainage Basin Water Delivery System (ULS).

UTAH LAKE DRAINAGE BASIN WATER DELIVERY SYSTEM

The Utah Lake Drainage Water Delivery System is the final component of the Bonneville Unit of the Central Utah Project. The ULS would complete the Bonneville Unit by delivering 60,000 acre-feet (74 million cubic meters) of water from Strawberry Reservoir to the Wasatch Front area for municipal and industrial (M&I) uses as shown on Figure 1. The ULS will address a wide range of environmental commitments made during construction of features of other systems of the Bonneville Unit while continuing to provide Bonneville Unit water in accordance with existing contracts. ULS pipeline facilities will provide a means to convey water to, and supplement the flow of the lower Provo River and Hobble Creek to facilitate efforts to recover the June sucker, an endangered fish. The Central Utah Water Conservancy District (District), the U.S. Department of Interior (DOI), and Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission) are Joint-Lead Agencies for NEPA compliance. These three agencies are responsible for planning, compliance with National Environmental Policy Act (NEPA), and implementation of the ULS.

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The goals of the ULS are to:

1. Develop, convey and deliver the remaining Bonneville Unit water supply for municipal and industrial uses and temporary agricultural supply along the Wasatch Front of Utah; and
2. Address the remaining environmental commitments of the Bonneville Unit associated with previously constructed systems.

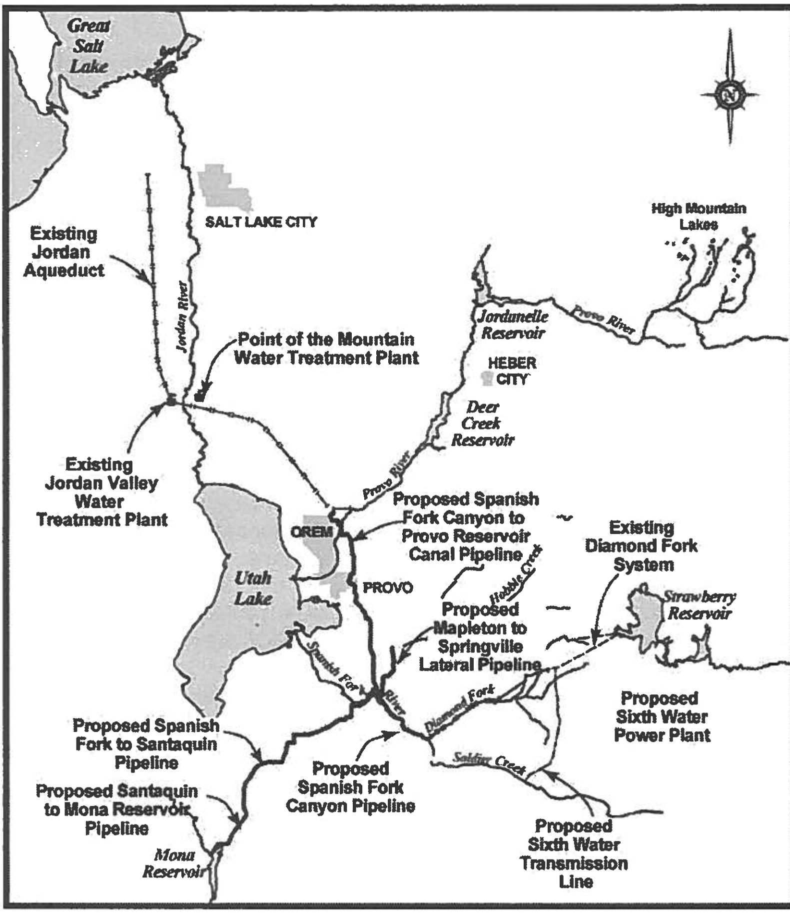

Figure 1: Utah Lake System Plan

ULS water would be contracted between the District and three water agencies who would distribute the water among their member agencies and commit to achieving the State of Utah water conservation goals. Two of these entities are Jordan Valley Water Conservancy District and the Metropolitan Water District of Salt Lake and Sandy located in Salt Lake County with some coverage in northern Utah County. These entities would take delivery of the ULS water near the Provo River and convey it northward to water treatment plants through the existing Jordan Aqueduct and the Provo Reservoir Canal.

The third entity is the South Utah Valley Municipal Water Association. The ULS would convey Federal water to turnouts constructed for the member cities, through the new Mapleton-Springville Lateral Pipeline and a new pipeline extending to Santaquin City to provide water for municipal secondary systems. In addition to ULS water, the new pipelines would convey up to 10,200 acre-feet (12.6 million cubic meters) of Strawberry Valley Project water on a space available basis for use within the boundaries of communities in southern Utah County.

NEED FOR THE ENVIRONMENTAL IMPACT STATEMENT PROCESS

The analysis of environmental impacts associated with a large water supply development project may be complex. The environmental impact statement (EIS) on a previously regulated river system rarely starts from a simple baseline condition. At the initiation of the environmental study, the issues, assumptions, and areal extent of the overall investigation are likely not known. The information needs associated with impacted or potentially impacted resources may not be clear. The selection of study tools may be problematic, and the schedule may be short. In this complex situation, the use of a flexible, yet comprehensive hydrologic analysis process will aid the hydrologist in meeting the EIS schedule and in developing the accurate information required for impact analysis by the other resource specialists.

The specific need that led to the development and refinement of this analysis process was the Utah Lake Drainage Basin Water Delivery System. A number of previous environmental documentation processes have been completed on the CUP, and the ULS project is designed to fit together with these documents as the final step.

Environmental analysis of potential ULS impacts required a detailed and complete hydrologic analysis study largely due to the complexity of the water supply setting of the Bonneville Unit (BU). In addition to providing an additional 60,000 acre-feet (74 million cubic meters) per year of new municipal and industrial (M&I) supply, the BU water supply uses water rights exchanges to firm-up the 107,500 acre-foot (133 million cubic meters) yield of the CUP M&I System. The M&I System's water supply is based on junior water rights in

Jordanelle Reservoir on the Provo River, and uses transbasin deliveries to the downstream Utah Lake to allow diversion of these rights. The exchanges from Utah Lake to Jordanelle Reservoir must be accomplished without degrading the quality of water in Utah Lake or impacting other upstream or downstream water users. Additionally, the needs of several endangered and threatened species, and developing minimum instream flow requirements must be considered. The multifaceted nature of the ULS clearly dictated the use of a systematic surface water analysis process.

THE ENVIRONMENTAL IMPACT STATEMENT PROCESS

The existence of a map implies to the traveler that someone has gone this way before. To the surface water hydrologist at the start of a large EIS, the optimum route to the end of the project may be extremely unclear. Even determining where to start may be difficult. Knowing or estimating all of the steps required to complete the study may be nearly impossible. The flowchart of the analysis process shown in Figure 2 provides the hydrologist with a basic roadmap through the six essential stages of an EIS.

Background

The first stage is background. It includes obtaining and reviewing previous studies (and particularly any previous NEPA documents) and the development of a clear understanding of the hydrologic setting of the proposed project. Available analysis tools and data should be identified and reviewed. One of the primary goals of this stage is to develop an understanding of the complexity of the hydrologic system and the resulting need for sophisticated analysis tools. This initial phase is critically important, in that it guides the data collection effort, the drafting of the Purpose and Needs statement, and the development of the project's baseline assumptions.

In the case of the ULS project, there have been at least five directly pertinent previous environmental documents in the impact area of influence. Because the ULS environmental study builds on the efforts and many of the effects of these previous studies, not only was careful review required, but matching hydrologic assumptions and initial conditions was also critically important.

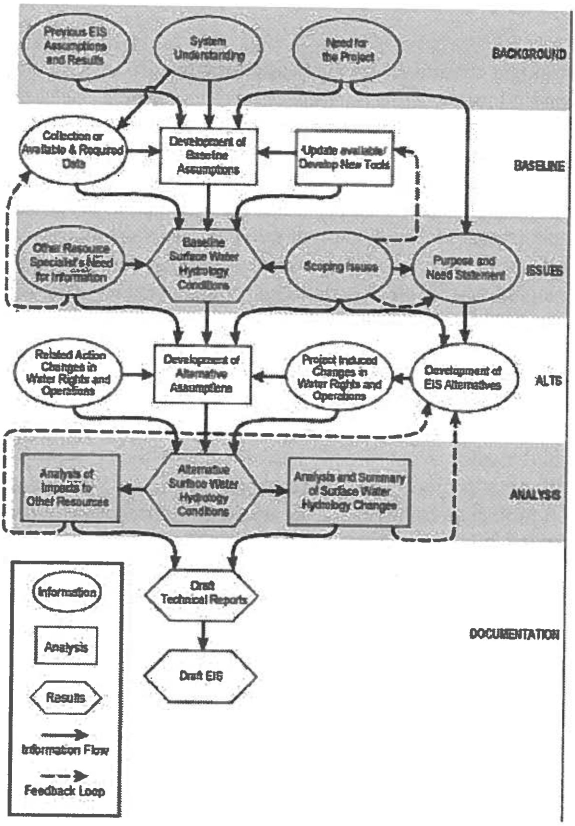

Figure 2. Hydrologic Analysis Process Flowchart

Baseline

Baseline hydrologic conditions are necessary for comparison with project alternative conditions, and for estimating alternative impacts. Selection of the wrong baseline may not only result in inaccurate estimates of impacts, but may force the project sponsors to mitigate for impacts that have little or nothing to do with their proposed actions. In the case of a project that has evolved over the years, with multiple phases or changes in the proposed plan, the baseline conditions must start at the conclusion of the previous environmental documentation. In the case of a river system where non-federal water use is an increasing or significant factor, it is particularly important to select the appropriate baseline development level.

The importance of this may be shown by considering the ULS setting. The Utah Lake hydrologic system anticipates increased withdrawals in the future, associated with growing demands for water. A significant portion of these increasing withdrawals are not directly associated with the ULS project, but are associated with other projects and non-federal water rights. But because the proposed ULS project alternatives will be analyzed under future hydrologic and water supply availability conditions, the baseline conditions (without the ULS alternatives) must also include certain future conditions. Otherwise, if existing withdrawals and streamflows are used in the baseline, but future withdrawals and streamflows are included in the alternatives, the proposed project's impacts would include the effect of all of the future, non-project depletions.

In the baseline stage, the available and required historical data are collected, and modeling tools are reviewed and/or developed. If previous NEPA analyses have been performed on the system, models and data may be available. Where possible it will be efficient to utilize existing, accepted models, since a new model is unlikely to provide exactly the same results as those previously documented. If existing tools are unavailable or inadequate, new tools would be developed in the baseline stage. Whether new models or old, the tools must be capable of transforming the available historical data into pre-project baseline conditions and into with-project alternative conditions.

The ULS project used a mix of new and old tools and data. The Provo River Simulation Model (PROSIM) had been previously developed to evaluate the hydrology and water rights of the Provo River and Utah Lake system. This model was used to develop much of the baseline hydrologic results. Previous environmental documents for the Bonneville Unit had been based on the 1930 through 1973 study period, while the 1950 through 1999 period was selected for the ULS study. This difference, plus a desire to improve upon study accuracy, dictated the development of new models and data for other parts of the study area and for impacts analysis. Specifically, five new spreadsheet models were created to track streamflows and lake contents within the ULS impact area.

Issues

The third stage of the modeling process includes participating in the drafting of the EIS Purpose and Needs Statement and project scoping, and communication with other resource specialists to insure that efforts to meet their needs for surface water results are included in the surface water modeling approach. In this stage the baseline conditions and hydrologic results are developed based upon the resource specialists' need for information, and based on issues received during EIS scoping.

This is the first stage with a clear feedback loop to the previous stage. Issues brought out during scoping and needs identified by other resource specialists may alter the need for surface water data or modeling capabilities. The project sponsor may have entered scoping with a preliminary purpose and need statement, which is subsequently modified based upon public and agency comments.

The connection between surface water hydrology and other EIS disciplines is very important. In a water supply project, surface water hydrology is frequently the central focus of environmental impacts. Stream flows, water deliveries, and reservoir levels directly or indirectly affect most other disciplines. Providing the precise information needed by the other disciplines is essential to completion of an adequate environmental analysis. An example of the extent of inter-connection between surface water hydrology and the other disciplines is shown in Figure 3. The relationships between disciplines displayed here were specifically taken from the ULS EIS, although the complexity is typical of many water supply impact studies.

Alternatives

A flexible and efficient surface water analysis process is most valuable during the alternatives development stage of the EIS. In this phase potential project alternatives are being considered and tested for their ability to meet project objectives without significant adverse impacts. This is also the stage in which related actions are being thought out for inclusion in the alternatives. The differentiation between related action changes and project induced changes in water rights and river system operations may be convoluted, but it is critical to the complete definition of project alternatives and the clear characterization of hydrologic modeling assumptions.

An effective modeling process will facilitate the testing of proto-alternatives, those conceptual ideas that may be worth a full examination, or may turn out to inadequately meet project goals. If the modeling tools and the modeling process are efficient, it will be a relatively simple matter to preliminarily test a number of

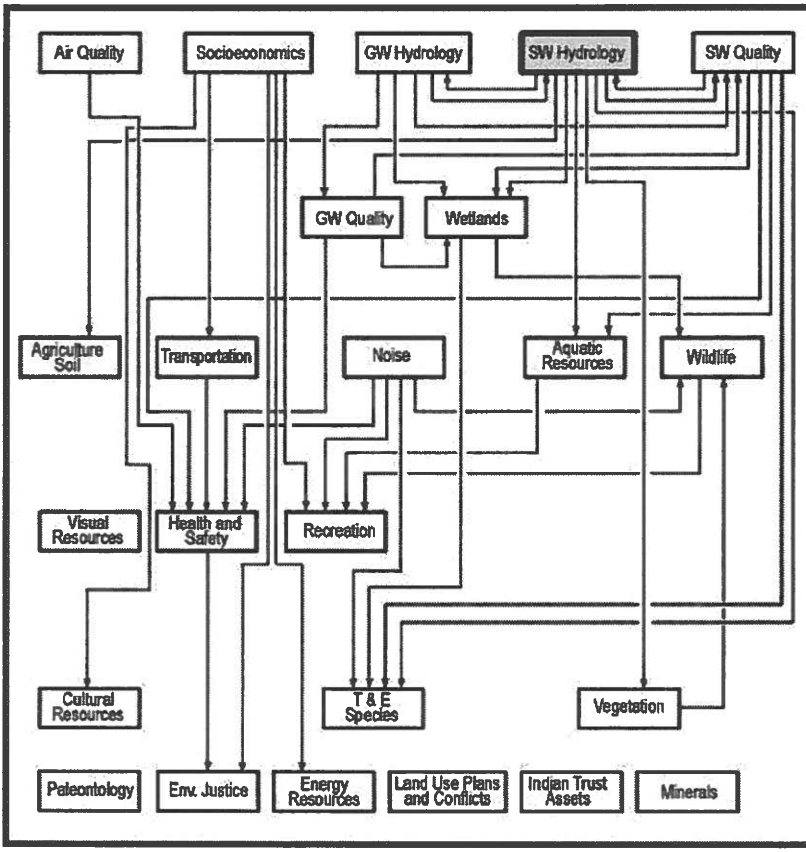

Figure 3. Typical Relationship between Surface Water Hydrology and other Disciplines - Utah Lake System EIS

proto-alternatives, and to thereby develop good, complete alternatives for further analysis.

In the ULS EIS, a number of proto-alternatives were considered, tested, refined, and sometimes discarded – prior to designing the two action alternatives included in the draft document. Furthermore, the potential operating plans and assumptions associated with each alternative were refined using the hydrologic analysis software to avoid unacceptable adverse impacts. In a tight water supply system like the Utah Lake watershed, this efficient testing of alternatives is extremely important to the timely completion of an EIS.

Analysis

If the previous stages have been completed adequately, the analysis phase will be straight-forward. The previously developed tools, assumptions, and alternatives are simply combined in an organized fashion, and the required information and results are generated and provided to the other discipline analysts. As the analysis stage progresses there may be a certain amount of iteration and evolution in the alternatives, but the analysis process should not be affected.

In the case of the ULS project, although there were a large number of changes in the project alternatives and the associated project assumptions, only one significant part of the hydrologic analysis process was changed. (A simpler piece of software was substituted for a more complicated model when the alternative streamflow impacts were found to be masked by secondary flow changes.) This is in spite of the fact that the overall study utilized nine different surface water models. Thus the use of an efficient analysis process simplified a very complicated water supply situation.

Documentation

Completion of the documentation stage is also facilitated by having an efficient surface water analysis process. Because the baseline and alternative modeling assumptions were clearly established in the prior phases, documentation of these elements should already be completed. Preparation of draft technical reports and memoranda, and of the appropriate surface water sections of the EIS simply involves re-stating the efforts completed in the background, baseline, issues, alternatives, and analysis stages. Numerical results are summarized in clear graphical and tabular forms. Complete numerical results are typically delineated in appendix materials. In the case of the ULS project, the Draft Surface Water Hydrology Technical Report included three volumes, with the second and third volumes consisting entirely of tables of hydrologic results.

CONCLUSION

The use of a complete hydrologic analysis process facilitated the completion of the draft EIS on the Utah Lake Drainage Basin Water Delivery System. The six stage process is appropriate as a guide in completing environmental analyses associated with other multifaceted water supply development projects. The review of appropriate background materials, development of a reasonable baseline condition, and clear understanding of the project issues were essential to starting the project off in the right direction. The efficient process and associated analysis software allowed the review and testing of a large number of proto-alternatives and operational assumptions. Even though the surface water setting of the Utah Lake watershed is extremely complicated, the use of the simple, six stage process made the hydrologic analysis more efficient and allowed completion of the project on a tight schedule.

COMPLETION OF THE DIAMOND FORK SYSTEM, A PART OF THE CENTRAL UTAH PROJECT

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ABSTRACT

The Diamond Fork System is located within Diamond Fork Canyon in Utah County, in the Uinta National Forest, 17 miles east of Spanish Fork, Utah. It was constructed for the Central Utah Water Conservancy District as part of the completion of the Central Utah Project. It is the link between Strawberry Reservoir and features of the proposed Utah Lake Drainage Basin Water Delivery System (ULS). The Diamond Fork System conveys water from Strawberry Reservoir through tunnels located near the crest of the Wasatch Mountain range into the Sixth Water Creek drainage basin located in Rays Valley. The original Strawberry Tunnel, constructed in 1912, has deteriorated and lost much of its carrying capacity, but is still used to provide instream flows and operation flexibility. The Diamond Fork System is used to convey most of the water from Strawberry Reservoir through the Syar Tunnel and the Sixth Water Aqueduct. From there the water flows through a series of tunnels, pipelines and siphons down Diamond Fork Canyon to the confluence of Diamond Fork Creek and Spanish Fork River where it will be connected to the proposed Spanish Fork Canyon Pipeline at the Spanish Fork River Flow Control Structure. The Diamond Fork System provides water to Utah Lake for exchange via Jordanelle Reservoir on the Provo River to Salt Lake and Utah Counties. The water conveyed through the Diamond Fork System will consist of a transbasin diversion from Strawberry Reservoir averaging 101,900 acre-feet of Central Utah Project water and 61,000 acre-feet of Strawberry Valley Project water per year. The water is used for irrigation, fish, wildlife, recreation, and municipal and industrial purposes. Included within the Diamond Fork System is the Syar Tunnel, Sixth Water Aqueduct, Diamond Fork Pipeline, and Upper Diamond Fork facilities. This system provides minimal environmental impact and the opportunity for restoration of riparian areas within the Sixth Water and Diamond Fork Drainages. Environmental damaging high flows will be removed from natural stream courses and minimum instream flows will be provided. This will allow for the restoration of a more natural ecosystem along Sixth Water and Diamond Fork creeks while providing a water supply needed to keep up with Utah's rapidly expanding population.

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BACKGROUND

The Strawberry Valley Project (SVP) was constructed by the Bureau of Reclamation (Reclamation) in the early 1900s. The Strawberry Dam was completed in 1912. At completion, Strawberry Reservoir had 283,000 ac-ft of storage. The Strawberry Tunnel was constructed between 1906 and 1922 as part of the SVP. It used the Diamond Fork watershed to transport water from Strawberry Reservoir to agricultural lands in Utah Valley. Water stored in Strawberry Reservoir was carried to the highest headwaters of Sixth Water Creek and subsequently flowed to Diamond Fork Creek.

In 1970-1973, Reclamation constructed the Soldier Creek Dam 7 miles downstream of the Strawberry Dam as part of the Central Utah Project. The Soldier Creek Dam increased the storage capacity of Strawberry Reservoir from 283,000 ac-ft to 1,106,500 ac-ft. By the time Soldier Creek Dam was completed, the Strawberry tunnel had deteriorated and lost much of its carrying capacity. It is still used to provide in-stream flows and operational flexibility; however, the Diamond Fork System now conveys the majority of the SVP water from Strawberry Reservoir through the Syar Tunnel and Sixth Water Aqueduct which were constructed and placed into service in 1996. These two facilities take water from Strawberry Reservoir and convey it to a point on Sixth Water Creek several miles downstream of the Strawberry Tunnel Outlet.

The Diamond Fork System will continue to transport SVP water as well as CUP M&I water stored in the enlarged Strawberry Reservoir.

INTRODUCTION

The Diamond Fork system was originally planned as part of the Central Utah Project (CUP) as authorized under the Colorado River Storage Project Act (CRSPA) of 1956. On October 30, 1992 the Central Utah Project Completion Act (CUPCA), was signed into law. CUPCA authorized the use of Federal funds to complete the Diamond Fork System with additional cost-sharing by the Central Utah Water Conservancy District (CUWCD). The Diamond Fork System is one of six systems that comprise the Bonneville Unit of the CUP. The Diamond Fork System serves as a link to deliver CUP and SVP project water from Strawberry Reservoir to Utah Lake and water users in the southern portion of Utah County. Deliveries to Utah Lake allow water previously delivered from Utah Lake to be stored on the Provo River in the Jordanelle Reservoir and delivered to Wasatch, Utah, and Salt Lake Counties.

Initially the Diamond Fork System incorporated both tunnel and pipeline segments connecting the Sixth Water Aqueduct with a to-be-built flow control structure in the Monks Hollow area. A Value Engineering team determined that a single tunnel might cost less to build, have less of an impact on the environment, and have a lower operations cost over the project's 50-year life cycle.

PROJECT FEATURES

Sixth Water Connection to Tanner Ridge Tunnel

The Sixth Water Connection is a 100-foot long box culvert and a 50-foot deep vertical shaft terminating at the upstream end of the Tanner Ridge Tunnel. This connection conveys water from the end of the Sixth Water Aqueduct to the Tanner Ridge Tunnel. A diversion box with an overflow weir and a discharge chute was constructed to allow a discharge of water from Sixth Water Aqueduct to Sixth Water Creek. The connection structure has a capacity of 660 cfs and a discharge chute capable of discharging up to 140 cfs to Sixth Water Creek.

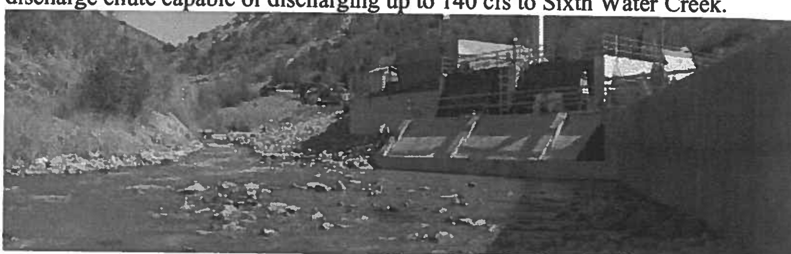

Figure 1. Sixth Water Connection Structure

Tanner Ridge Tunnel

The Tanner Ridge Tunnel crosses 50 feet under Sixth Water Creek and through Tanner Ridge which is located between Sixth Water Creek and Diamond Fork Creek. The tunnel was constructed through the upper member of the Red Narrows Conglomerate and the Flagstaff Formation consisting mainly of limestone, siltstone and conglomerate and was excavated with a tunnel boring machine (TBM) to a diameter of 150-inches and later concrete lined to a diameter of 126-inches. This low pressure tunnel has a capacity of 660 cfs, and is 5,194 feet in length.

Figure 2. Excavated Tanner Ridge Tunnel

Upper Diamond Fork Pipeline

The Upper Diamond Fork Pipeline is a welded steel pipe 96-inches in diameter, 5,485 feet in length and has a capacity of 660 cfs. The pipeline connects the Tanner Ridge Tunnel to the Upper Diamond Fork Flow Control Structure.

Figure 3. Upper Diamond Fork Pipeline

Upper Diamond Fork Flow Control Structure

The Flow Control Structure consists of a 0.4 acre underground structure with a buried pipeline bifurcation. It contains an underground vault housing cone valves and sleeve valves with the roof slab at ground level. The pipeline bifurcation splits the 660-cfs flow into two 54-inch diameter pipes that convey the water through two 48-inch cone valves and two 48-inch sleeve valves. The cone valves serve as guard gate valves and the two sleeve valves are capable of throttling the flows and dissipating the pressure in the water before it enters the vortex shafts. The flow control facilities are operated electronically from the control building located adjacent to the vortex shafts.

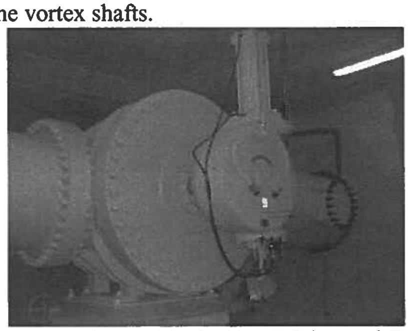

Figure 4. 48-inch Cone Valve Inside the Upper Diamond Fork Flow Control Structure

Diamond Fork Shafts

The Diamond Fork Shafts consist of three 78-inch diameter vertical shafts – two vortex shafts for conveying water down to the aeration chamber and then to the Diamond Fork Tunnel, and one ventilation shaft. The vortex shafts dissipate most of the energy as the water flows down the shafts in a vortex motion. The ventilation shaft serves two purposes; allowing for the passage of air from the aeration chamber to the surface and providing maintenance access to the aeration chamber and tunnel downstream. Each shaft is 187.5 feet deep and the two vortex shafts have a capacity of 330 cfs each for a total capacity of 660 cfs.

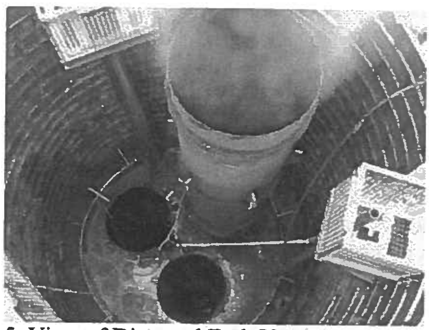

Figure 5. View of Diamond Fork Vortex and Ventilation Shafts

Aeration Chamber and Connecting Tunnel

The aeration chamber is 16 feet wide, approximately 67 feet in length and is located at the bottom of the vortex shafts. The aeration chamber has a cathedral arch type cross section that varies from 16 feet to 10.5 feet in height. Three rows of concrete dentates were constructed in the floor at the downstream end of the chamber. The dentates dissipate any remaining energy the water collects from the fall down the vortex shafts. The connecting tunnel makes the transition from the cathedral arch section to a 126-inch diameter circular tunnel section and is approximately 112 feet in length. Both the aeration chamber and the connecting tunnel were constructed in bedrock, lined with reinforced concrete, and have a capacity of 660 cfs.

Figure 6. View of Aeration Chamber with Vortex Shafts at the end.

Diamond Fork Tunnel

The Diamond Fork Tunnel was excavated with a TBM through the lower and middle members of the Red Conglomerate formation consisting of conglomerate, sandstone and some limestone. The tunnel was excavated to a diameter of 150-inches and concrete lined to a diameter of 126-inches. Approximately 760 feet of the concrete lining was reinforced as ground conditions warranted. The tunnel conveys 660 cfs, and is 13,114 feet in length.

Figure 7. Upper Diamond Fork Tunnel with concrete lining.

Monks Hollow Overflow Structure

The 40-foot long Monks Hollow Overflow Structure is located at the Diamond Fork Tunnel outlet portal. The structure contains two chambers mostly underground with only the top of the structure visible at the surface. The first chamber receives flows from the pipeline exiting the tunnel and connects to the Diamond Fork Pipeline Extension with a capacity of 560 cfs. This chamber has an internal overflow weir that discharges into the second chamber connected to the 84-inch diameter RCP discharge pipeline with a capacity of 660 cfs. The discharge pipeline is 1074 ft long and connects to the Diamond Fork Creek

Outlet. The overflow structure provides a free water surface to discharge in-stream and excess flows into Diamond Fork Creek and prevents excess head on the Diamond Fork Pipeline.

Figure 8. View of construction of Monks Hollow Overflow Structure

Diamond Fork Creek Outlet

The Diamond Fork Creek Outlet is an energy dissipation structure which discharges to a 350-foot long open channel tributary to Diamond Fork Creek. The energy dissipation structure is a 40-by-10 foot concrete vault with internal baffles to slow the water velocity before discharging it into the constructed open channel. A rock riprap grade control is constructed between the energy dissipation structure and Diamond Fork Creek to maintain the existing floodplain grade and protect the energy dissipation structure during high runoff flows. The Diamond Fork Creek Outlet conveys the minimum streamflows while serving as an emergency overflow and bypass outlet into Diamond Fork Creek.

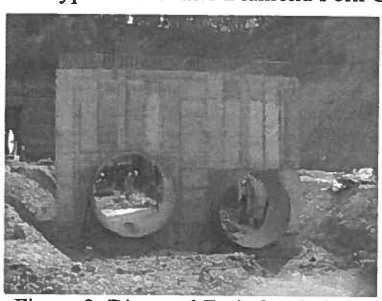

Figure 9. Diamond Fork Creek Outlet

Diamond Fork Pipeline Extension

The Diamond Fork Pipeline Extension has a capacity of 560 cfs, is a welded steel pipe 96-inches in diameter, and has a length of 6,364 feet. The structure connects Monks Hollow Overflow Structure to the upstream end of the Diamond

Fork Pipeline. Most of the pipeline was installed under the realigned and improved Diamond Fork Road.

Diamond Fork Pipeline

The Diamond Fork Pipeline is 7.2 miles long and extends from the Spanish Fork River at the mouth of Diamond Fork Canyon to the Diamond Fork Pipeline Extension. The pipeline parallels or underlies the Diamond Fork Road. This segment of the Diamond Fork System was previously completed in 1997.

Figure 10. Diamond Fork Pipeline.

Spanish Fork River Flow Control Structure

The Spanish Fork River Flow Control Structure was constructed at the mouth of Diamond Fork Canyon adjacent to Highway 6 in Spanish Fork Canyon. This structure employs two 42-inch diameter cone valves, utilized as guard gate valves, and two 42-inch diameter sleeve valves to break the pressure and throttle the flows from the Diamond Fork Pipeline. Water from the sleeve valves pool in the vault and overflow into a box culvert which discharges directly into Diamond Fork Creek. This structure was constructed such that in the future the water can flow past this structure into the Spanish Fork Canyon Pipeline which is a proposed component of the Utah Lake System.

Figure 11. Spanish Fork River Flow Control Structure under construction

SYSTEM CONTROLS

System controls and instrumentation is provided through a new fiber optic line running the full length of the project in the pipeline trenches and tunnel linings. Complete system monitoring and controls are hardwired at each of the flow control structures: Sixth Water Creek, Upper Diamond Fork Flow Control Structure, Monks Hollow, and Spanish Fork River Flow Control Structure. This allows for control of all system components from any of the structures. Normal operations are controlled remotely from CUWCD's main operations center in Orem, Utah.

Figure 12. Control room for the Upper Diamond Fork Flow Control Structure

SUMMARY

The Diamond Fork System fulfills many purposes and needs for the public and the environment. The system now allows us to maintain the statutorily mandated minimum flows in Diamond Fork Creek and Sixth Water Creek. It also removes the high flows brought over from Strawberry Reservoir into the Sixth Water and Diamond Fork creek drainages. The completed Diamond Fork System meets the CUWCD's municipal and industrial water contractual commitments to Salt Lake, Utah, and Wasatch Counties by conveying Bonneville Unit water to Utah Lake via the new features for exchange to Jordanelle Reservoir and historical Strawberry Valley Project irrigation water. Finally, the new system will provide the opportunity and flexibility for restoration of aquatic and riparian habitat in Sixth Water and Diamond Fork creeks to protect water quality and threatened species in Diamond Fork Creek.

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DROUGHT PLANNING FOR THE CITY OF FARGO, NORTH DAKOTA

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ABSTRACT

Over the last 10 years, many communities in North Dakota have experienced moderate to severe flooding. Many of these communities have developed response plans to react to these flood problems. In contrast, during the last two years, much of North Dakota has experienced moderate to severe drought conditions. While some communities have water conservation plans or drought management plans to respond to drought conditions, many of these plans are outdated and lack the necessary framework for monitoring or responding to drought conditions. This paper outlines the methodology and procedures used for drought planning for a community in North Dakota using the City of Fargo Drought Management Plan as an example.

INTRODUCTION

The City of Fargo, being the largest population center in eastern North Dakota, is susceptible to water supply shortages. The current water supply for the City of Fargo consists of the Red River of the North and the Sheyenne River. The City also has water rights for Lake Ashtabula, located on the Sheyenne River upstream from Valley City, North Dakota. These surface water sources are subject to low watershed yields during drought years. The U.S. Bureau of Reclamation completed a Water Needs Assessment for municipal, rural, and industrial water supply within the Red River Valley in 2000. The Needs Assessment projected severe water shortages throughout a planning horizon extending to the year 2050, should a severe drought of both magnitude and duration be experienced similar to that of the 1930s. Although other efforts are currently being made to provide a reliable water supply for eastern North Dakota from the Missouri River and other sources (i.e., the Dakota Water Resources Act), the City of Fargo decided that a formal mechanism needed to be in place to deal with short-term water shortages through the implementation of a Drought Management Plan.

In 2002, the City of Fargo commenced the development of a formal document the City could use to regulate and reduce water usage during periods of low flow on the Red River and Sheyenne River. The City desired the plan to include items such as a formal monitoring procedure, target water levels for a phased

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conservation plan, and alternative conservation methods. Working closely with the City of Fargo, Houston Engineering, Inc., provided technical expertise to complete this complex project. The Drought Management Plan was completed and formally adopted by the Fargo City Commission in 2003. The City of Fargo is currently developing a formal Drought Ordinance as well as a water rate structure geared towards demand reduction during drought conditions.

WATER SUPPLY AND USE

Water Supply

The State of North Dakota uses the prior appropriation doctrine as the foundation for establishing water rights. Under this doctrine, the first user of water acquires a priority for the use of that water. This principle is sometimes referred to as "first in time is first in right." The City of Fargo has three permits for raw water supply. They include:

- Water Permit #749

Source:	Red River of the North
Quantity:	109,500 acre-feet/year
Pumping Rate:	150 cfs (97 MGD)
Priority Date:	January 30, 1957

- Water Permit #4718

Source:	Sheyenne River
Quantity:	7,000 acre-feet/year
Pumping Rate:	25 cfs (16 MGD)
Priority Date:	August 27, 1993
Special Conditions:	

  1) Minimum Sheyenne River flow at Horace gauging station = 50 cfs.
  2) Annual usage of the 7,000 acre-feet or a portion thereof is subtracted from Permit #749 allocation.

- Water Permit #1091

Source:	Sheyenne River (Lake Ashtabula)
Quantity:	35,880 acre-feet/year
Pumping Rate:	54 cfs (35 MGD)
Priority Date:	June 27, 1963

The primary water supply source for the City of Fargo is the Red River of the North under Water Permit #749. During periods of low flow or periods of poor water quality on the Red River, the City of Fargo draws water from the Sheyenne River under Permit #4718. During periods of low river flows on the Red River and Sheyenne River, the City of Fargo can request the State Engineer and U.S. Army Corps of Engineers to release water from Lake Ashtabula under Water Permit #1091 to satisfy Fargo's water supply needs. The rate of release from Lake Ashtabula is based upon the river flow, senior appropriation requirements, and the City of Fargo's withdrawal rate.

Water Use and Water System Capacities

Currently, Fargo's Red River raw water pump station has a firm capacity of 30 million gallons per day (MGD). The Red River intake is designed to handle 45 MGD. The Sheyenne River raw water pump station has a maximum capacity of 16 MGD. A second pump in the station can pump about 10 MGD. Only one pump can run at a time. The Sheyenne River intake has a capacity of 45 MGD. The capacity of the Fargo Water Treatment Plant (WTP) is 30 MGD and is expandable to 45 MGD. In 2000, the peak daily water demand in Fargo was 21.7 MGD.

Upstream Reservoirs

The water supply for Fargo is influenced by three reservoirs operated by the U.S. Army Corps of Engineers. They include Baldhill Dam and Lake Ashtabula on the Sheyenne River, Orwell Dam and Reservoir on the Ottertail River, and Lake Traverse Project on the Bois De Sioux River. Following is a brief description of these reservoirs:

Baldhill Dam and Lake Ashtabula. Baldhill Dam is located on the Sheyenne River, 271 river miles from the confluence of the Sheyenne River and the Red River of the North. Baldhill Dam was constructed in 1950. Baldhill Dam and Lake Ashtabula were authorized and are regulated for low-flow augmentation to meet downstream water supply and pollution abatement requirements and for alleviating flooding downstream in the Sheyenne River valley. In addition to these primary objectives, the reservoir is regulated with proper regard to other functions, including recreation and fish and wildlife conservation. The elevation of the conservation pool for Baldhill Dam is 1266 msl. At this level, the dam stores 70,600 acre-feet of water.

Orwell Dam and Reservoir. Orwell Dam is located on the Otter Tail River at River Mile 38.6 in southwestern Otter Tail County, Minnesota. It is approximately 55 miles southeast of Fargo, North Dakota. Orwell Dam and Reservoir was originally a dual-purpose project designed to impound water during flood periods and to release stored water for water supply and pollution abatement during low-flow periods. Changes in the Red River of the North basin have diminished the water supply and pollution abatement role of the reservoir, however flood control remains a major purpose of the project. The elevation of the conservation pool for Orwell Dam is 1064 msl. At this level, the dam stores 8,300 acre-feet of water.

Lake Traverse Project. The Lake Traverse Flood Control Project is located on the boundaries of Minnesota, North Dakota, and South Dakota. The project lies within Traverse and Wilkin Counties, Minnesota, Richland County, North Dakota, and Roberts County, South Dakota. The project was authorized for flood control, water conservation, and other purposes. The Lake Traverse Project consists of the Browns Valley Dike, Reservation and White Rock Dams and associated reservoirs, and the Bois de Sioux River channel. The reservoir behind Reservation Dam is named Lake Traverse.

During periods of low flow, regulation of Lake Traverse will be coordinated with that of Orwell Reservoir on the Otter Tail River and with Lake Ashtabula on the Sheyenne River, to supplement natural flows on the Red River of the North for water supply and pollution abatement. According to the water control plan, flows for water supply or other instream purposes can be made until Reservation Pool in Lake Traverse drops to elevation 974.0 msl. If the lake is at the conservation pool level of 976 msl when the drought begins, this will be 21,000 acre-feet

DROUGHT INDICATORS

Unlike many other emergency situations, drought severity develops over time and therefore presents the opportunity to develop and implement appropriate measures before the situation worsens. Several indicators are available to monitor and assess the severity of a drought, or drought level. Four indicators were used as part of the Drought Management Plan to monitor conditions that may impact the quantity and quality of water available to the City of Fargo. These include the Standardized Precipitation Index, the Palmer Drought Severity Index, Streamflow Conditions, and Reservoir Storage. Following is a description of these indicators:

Standardized Precipitation Index (SPI)

Precipitation records are one of the most useful and readily available data for monitoring drought conditions on a meteorological basis. Such records are available on national, state, and regional levels, and long-term historical patterns of rainfall can be determined.

The Standardized Precipitation Index (SPI) was developed with the understanding that a deficit of precipitation has different impacts on the water resources in an area and was designed to quantify the precipitation deficit for multiple time scales. The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. The SPI quantifies the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. The SPI is available for the 1-, 3-, 6-, 9-, and 12-month time periods. Table 1 summarizes the drought severity based on the SPI.

Table 1. Drought Severity based on SPI

+2.0 or more	Extremely Wet
+1.5 to +1.99	Very Wet
+1.0 to +1.49	Moderately Wet
-0.99 to +0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and below	Extremely Dry

Palmer Drought Severity Index (PDSI)

The PDSI is a widely used scale for measuring drought conditions. The PDSI provides a standardized means of depicting drought throughout the continental United States. It measures the departure of water supply (in terms of precipitation and stored soil moisture) from demand (the amount of water required to recharge soil and keep rivers, lakes and reservoirs at normal levels). The PDSI calculations are made for 350 climatic divisions in the United States and disseminated by the US National Weather Service on a weekly basis.

Normal weather has an index value of zero in all seasons in any climatic region. Droughts have negative index values, while wet periods have positive values. Consecutive negative values can provide initial warning of a developing drought. During drought, the magnitude of negative values indicates drought severity. Table 2 summarizes the drought severity based on the PDSI.

Table 2. Drought Severity based on PDSI

Above +4.0	Extreme Moist Spell
+3.0 to +3.9	Very Moist Spell
+2.0 to +2.9	Unusual Moist Spell
+1.0 to +1.9	Moist Spell
+0.5 to +0.9	Incipient Moist Spell
+0.4 to -0.3	Near Normal
-0.4 to -0.9	Incipient Drought
-1.0 to -1.9	Mild Drought

-2.0 to -2.9	Moderate Drought
-3.0 to -3.9	Severe Drought
Below -4.0	Extreme Drought

Streamflow Conditions

Streamflow gauging station data may be analyzed statistically in a number of different ways for possible indication of drought conditions. Monthly flow duration data is one of the most useful. It shows the percent of time given flows are equaled or exceed on a monthly basis during the period of record.

The monthly flow duration table is a magnitude and frequency analysis of daily discharge values. It is computed by tabulating the number of daily discharge values that fall within preselected class limits, computing the percentage of values within each class, and interpolating discharge values for the percentages shown in the table. Drought status is determined from stream flows based on exceedances, which are similar to percentiles. A 75 percent exceedance flow value means that the current monthly flow is exceeded in the stream 75 percent of the time, or the monthly average flow in the stream is less than that value only 25 percent of the time. By using monthly flow-duration data, seasonal variability is considered and various ranges can be established equivalent to drought stages.

The U.S. Geological Survey (USGS) maintains a network of stream gages across the Red River Valley. The discharge data, along with monthly flow duration tables for the stream gages can be used to monitor drought conditions and help determine the drought stage. The following stream gages are being monitored for drought purposes:

1. Sheyenne River near Cooperstown, ND – USGS Gage Number 05057000

2. Sheyenne River below Baldhill Dam, ND – USGS Gage Number 05058000

3. Sheyenne River near Kindred, ND – USGS Gage Number 05059000

4. Otter Tail River below Orwell Dam near Fergus Falls, MN – USGS Gage Number 05046000

5. Bois De Sioux River near White Rock, SD – USGS Gage Number 05050000

6. Red River of the North at Fargo, ND – USGS Gage Number 05054000

Reservoir Storage

Reservoir or lake storage is a common indicator of drought conditions and potential water shortages. The water supply for Fargo is influenced by three reservoirs operated by the U.S. Army Corps of Engineers. They include Baldhill Dam and Lake Ashtabula on the Sheyenne River, Orwell Dam and Reservoir on the Ottertail River, and the Lake Traverse Project on the Bois De Sioux River.

DROUGHT LEVELS

The drought management plan was developed to provide a document that defines the conditions under which a drought-induced water supply emergency exists for the City of Fargo and specifies the actions that are to be taken in response. The drought management plan clearly establishes the criteria for action at each stage of shortage.

The format for this plan is based on a variation of a plan format provided by the American Waterworks Association in their Drought Management Handbook. The classification scheme is modeled after the National Weather Service's Watch/Warning program. In order to assess the severity of a drought, five levels of drought have been identified: Normal, Advisory, Watch, Warning, and Emergency. The levels provide a basic framework from which to take actions to assess, communicate, and respond to drought conditions. The drought levels are progressive based on a continuation and/or worsening of drought conditions. Likewise, as drought conditions improve, the drought levels go back down progressively once the drought criteria for the level are no longer met. The drought level is established by monitoring the four drought indicators described previously. The protocol for determining the drought level is that 3 out of 4 parameters must indicate a given phase before that drought phase is declared. Following is a description of the drought levels for the City of Fargo Drought Management Plan.

Phase 1 – Normal Conditions

When the water supply for the City of Fargo is not in a drought condition, this phase of the Drought Management Plan is in place. Normal conditions are depicted by adequate water supply and acceptable water quality. Normal conditions are defined by the following indices:

Index	Value
SPI	-0.99 and higher
PDSI	-1.9 and higher
Stream Flow	Flow is greater than 65% excedence monthly flow duration value

Reservoir Levels	Baldhill Dam, Orwell Dam, and Lake Traverse have been drawn down below their maximum drawdown (minimum pool) levels. Runoff projections remain low.

DROUGHT RESPONSE

A Drought Declaration triggers a number of program responses. Conservation efforts which are on-going will receive additional emphasis. The level of drought response will vary depending on the level of the drought. Generally, measures placed in effect at lower response levels will remain in effect at more stringent response levels, and additional measures or actions added. The Drought Management Plan outlines drought response efforts for the City of Fargo for each drought condition. The plan also contains a sample Drought Declaration that can be used to formally implement response efforts under this Drought Management Plan. Response efforts for the City of Fargo will be further defined as part of the development of the Drought Ordinance.

CONCLUSIONS

The question of when water use reductions become necessary is not a simple one to answer. Demand reduction may be necessitated by a number of factors impacting on the City's water supply. It is likely the public will question and scrutinize the need for implementing these demand reduction measures. A Drought Management Plan can provide a mechanism for monitoring water supply conditions, establishing demand reduction goals for given drought levels, and public education of the need for demand reduction measures. Other important steps in effective drought management are to establish a Drought Ordinance and water rate structure that provide an enforcement mechanism for the Drought Management Plan.

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