Irrigation District Sustainability — Strategies to Meet the Challenges

A USCID Irrigation District Specialty Conference

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Preface

The papers included in these Proceedings were presented during the **USCID Irrigation District Specialty Conference**, held June 3-6, 2009, in Reno, Nevada. The Theme of the Conference was ***Irrigation District Sustainability — Strategies to Meet the Challenges***. An accompanying book presents abstracts of each paper.

The success or failure of today's irrigation districts rests with the long and short term decisions made by the management staffs of those institutions. Often those decisions are predicated on the direction provided by elected officials — officials who, again, rely upon the expertise and professional judgment of district staff and consultants. That responsibility demands the continuing development of tools, knowledge and skills to make good decisions.

The diversity and complexity of issues facing irrigation districts today seems at times to be overwhelming. Many irrigation districts are celebrating 50- and 100-year anniversaries and are faced with rebuilding and modernizing their aged infrastructure. Most districts are facing legal challenges to their water rights or water supply contracts, dealing with changing, ever-tightening water quality regulations, and wrestling with environmental issues. Water marketing has surfaced as a means for some districts to insure financial security, while other districts with less plentiful supplies are having to achieve higher levels of operational efficiency to cut costs and accomplish more with less. While dealing with all that, districts must address the everyday tasks of managing personnel, ensuring worker safety, managing district assets, addressing urban encroachment and controlling costs.

The papers presented during the Conference focused on these issues. Concurrent technical sessions addressed the following topics: **Administration, Policy and Governance**; **Construction, Maintenance and Environmental Issues**; **Water Operations;** and **Engineering**; papers presented during the Opening Plenary Session and a Poster Session are also included in the Proceedings.

The authors are professionals from academia; federal, state and local government agencies; water and irrigation districts; and the private sector.

USCID and the Conference Chairman express gratitude to the authors, session moderators and participants for their contributions.

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Conference Chairman

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ISSUES AND CONSIDERATIONS RAISED WHEN DISTRICT ACCEPTS MUNICIPAL WATER INTO IRRIGATION CANALS

Cortney D. Duke[1]

ABSTRACT

Throughout the Northwest, irrigation districts allowed or turned a "blind eye" to nearby growing cities' use of their irrigation ditches and agricultural drains for storm water runoff or wastewater discharge (collectively "municipal water"). As urbanization continues to increase, the demand on districts' canals reaches new heights. Increased demand, coupled with more environmental concerns and regulatory oversight, causes many districts to re-evaluate acceptance of urban, suburban and municipal water in their irrigation canals or agricultural drains.

Prior to accepting municipal water, districts must consider and determine several issues. First, a district must consider whether it may even accept the municipal water pursuant to its authorizing statute[2] and its own organizational by-laws, rules and regulations. Second, a district must consider if it has sufficient control over its facilities for additional inputs and outputs to the system facilities. Third, a district should consider the impacts the storm water will have on its users. Specifically, a district must consider and weigh the impact on: (1) district operation and maintenance; (2) potential district liability; and (3) possible financial benefits. Finally, if a district determines it has the necessary authority to accept municipal water, it must consider whether it is in the best interest of the district to proceed and how to protect the district's interests and facilities in the process. It is imperative that the terms and conditions of the municipality's use of the district's canals and drains be specifically detailed in a storm water contract or other intergovernmental agreement.

INTRODUCTION

As any special district manger knows, a district must continually respond to the changing world to protect its purpose and facilities. Increased urbanization is a 21st century challenge facing special districts, including irrigation districts. As the rate of urbanization grows so does the rate of production of municipal storm water runoff and municipal wastewater discharge (collectively "municipal water"). Throughout the Northwest, special districts have allowed nearby growing cities to use their existing irrigation ditches and agricultural drains for discharge and delivery of municipal water. However, as urbanization and corresponding regulatory oversight continue to increase the demand on districts' canals has reached new heights. Coupled with more environmental concerns and regulatory oversight, increased demand has caused many districts to re-evaluate whether to accept urban, suburban and municipal water in their irrigation canals or agricultural drains.

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[2] For example, irrigation districts formed in Oregon under Oregon Revised Statute ("ORS") 545 have no specific authority to accept municipal water.

From a city's perspective, utilizing the existing delivery and drainage infrastructure is an attractive prospect. From the district's perspective, allowing a city to use its canals presents legal, financial and political considerations. An irrigation district's decision to accept municipal water must be carefully weighed and measured. The decision will be fact specific to each irrigation district and may involve issues such as historical use, facility capabilities, federal and state regulation, and liability.

This paper will discuss the issues and considerations associated with accepting municipal water in the context of a scenario focusing primarily on an irrigation district formed in the State of Oregon. However, the issues and considerations apply similarly to other specials districts formed for the purpose of delivering or draining agricultural lands.

The Scenario

Water Irrigation District ("District") delivers irrigation water to 3,400 acres of irrigable land. The District was formed under Oregon Revised Statute 545 (the irrigation district law) in 1970 and its delivery canals and drainage ditches were constructed at the turn of the century.

Oregon State City ("City") is a municipal corporation duly organized and existing under and by the virtue of the laws of Oregon. In recent years, City has experienced increased growth and twice extended its urban growth boundary. City has begun to produce additional storm water runoff and wastewater (collectively "municipal water") as a result of its increased density and growth.

City officials attend a public meeting of the District and request permission to utilize the District's existing canals and ditches for discharge of the City's municipal water. Before the District may agree to accept municipal water from the City the District must consider and determine the following questions:

1. Does the District have the necessary authority to allow the City to use its irrigation facilities?

2. Does the District have sufficient control of its canals and ditches?

3. What impacts will the municipal water have on the District's operational and maintenance activities? On water quality and quantity? On the District's potential tort and civil liability? On the District's financial resources?

4. How can the District most effectively accept the municipal water while protecting the best interests of the District?

<u>Does the District have the authority to accept municipal water?</u>

Authority for the District to accept the municipal water may come from the District's authorizing statute, the District's own organizational by-laws, by resolution of the Board of Directors or a combination of all three.

<u>Authorizing Statute</u>-Each special district in Oregon is formed for a specific purpose. Irrigation districts in Oregon are formed under ORS 545, known as the Irrigation District Law. Pursuant to ORS 545.025, an irrigation district is formed "to provide for the construction of works for irrigation of [their] land, to provide for the reconstruction, betterment, extension, purchase, operation or maintenance of works already constructed, or to provide for the assumption of indebtedness to the United States incurred under the federal reclamation law on account of their lands." The delivery and transmission of municipal water is not specifically prohibited in the allowable purposes of irrigation district formation. The District must consider whether accepting municipal water is allowable under its authorizing statute.

Consider that other special districts may be formed for more broad public benefit purposes, such as:

Drainage Districts formed pursuant to ORS 547, are formed for the purpose of "of having such lands reclaimed and protected by drainage or otherwise from the effects of water, for sanitary or agricultural purposes, or when the same may be conducive to the public health, convenience and welfare or of public utility or benefit." ORS 547.005.

Water improvement districts, formed pursuant to ORS 552, are formed for the purpose of **"**acquiring, purchasing, constructing, improving, operating and maintaining drainage, irrigation, and flood and surface water control works in order to prevent damage and destruction of life and property by floods, to improve the agricultural and other uses of lands and waters, to improve the public health, welfare and safety, to provide domestic or municipal and industrial water supply, to provide water-related recreation and for the purpose of enhancing water pollution control, water quality, and fish and wildlife resources." ORS 552.108.

A water control district, formed pursuant to ORS 553, is formed for the purpose "of acquiring, purchasing, constructing, improving, operating and maintaining drainage, irrigation, and flood and surface water control works in order to prevent damage and destruction of life and property by floods, to improve the agricultural and other uses of lands, and to improve the public health, welfare and safety. (2) A water control district, organized for one or more of the purposes provided by subsection (1) of this section, may also acquire, purchase, construct, improve, operate and maintain works and facilities for the secondary purposes of domestic, municipal and industrial water, recreation, wildlife, fish life and water quality enhancement. However, a water control district may not be created solely for one or more of the purposes provided by this subsection." ORS 553.020(1 – 2).

A special district formed with a public use component may have a much clearer authorization for accepting municipal water in its canals and ditches. However, an irrigation district has additional powers proscribed throughout ORS 545 that may create the necessary authority. Irrigation districts generally have only those powers that are specifically granted by statutes, by express or clear implication. *Redmond Realty Co. v. Central Oregon Irrigation District*, 140 Or 282, 12 P2d 1097 (1932). An irrigation district has the power to enter into contracts and manage the affairs of the district pursuant to ORS 545.221 which may have the implied power to accept municipal water in its system.

An irrigation district has the additional enumerated power to acquire and operate municipal water systems under ORS 545.257. As part of this power, the district is authorized to (1) acquire by gift, purchase, or other legal means, domestic and municipal water works or water systems; (2) construct or maintain domestic and municipal water works or systems; (3) furnish water for domestic municipal uses to premises and inhabitants within its district. The authority of the district to acquire, construct and operate an municipal water system is qualified by the final provision of ORS 545.257(3), which provides that "the power to furnish water for domestic and municipal uses granted by this section shall not be exercised in such a manner as to impair the service of the district in furnishing water for irrigation purposes."

Thus, the power of the District to accept municipal water in its canals and ditches is not specially allowed or prohibited by the authorizing statute. Under ORS 545, the District may have the implied power to accept and allow the municipal water pursuant to its other powers. However, it is clear that should the District find it has the power to accept the municipal water the District must ensure the decision is in the best interest of the District and will not impair the District in its primary purpose of delivering water for irrigation purposes.

The District may establish that accepting the municipal water is in the best interest of the District through analysis of its Organizational By-Laws or a specific resolution.

<u>Organizational By-Laws</u>-Even where a special district's authorizing statute may provide for the acceptance of municipal water, the District must also confirm the acceptance of municipal water does not conflict with the organizational purpose. A district contemplating the acceptance of municipal water in its canals should confirm that its own formation documents, whether Articles of Incorporation or By-Laws allow or at minimum do not prohibit, accepting municipal water. Similarly, the District may establish that the acceptance of municipal water is within the purposes for which the District was formed by including the necessary provision in the organizational By-Laws or other documents.

The Board of Directors of nearly every special district has the discretionary authority to establish equitable By-Laws or rules and regulations for the broad administration and management of the water delivery district. ORS 545.221 provides that the Board of Directors of an irrigation district shall "establish equitable bylaws, rules and regulations for the administration of the district and for the distribution and use of water among the landowners." Similarly, the board of directors of a water improvement district are authorized to "establish reasonable rules and regulations for the administration of the affairs of the district" ORS 552.223(3). A water control district board of directors is similarly authorized to "Establish reasonable rules and regulations for the administration of the affairs of the district." ORS 553.230(5).

A special district desiring to accept municipal water, but lacking specific statutory authority to do so, should ensure its By-Laws or rules and regulations recognize and allow for the acceptance of municipal water. If a review of the organizational By-Laws does not reveal the necessary authority, the District's Board of Directors should review relevant law on amending the organizational documents to include the necessary provision.

Resolution-A special district is a public body, so all decisions and acts of the governing board are made by resolution. The board creates a public record of the district's declaration of its decision to accept municipal water by making and recording the resolution to accept municipal water. The governing body of any special district that decides to accept municipal water should pass a confirming resolution regardless of whether the authorizing statute or organizational documents already allow the acceptance of municipal water. The legislative or specific power of the District to accept municipal water is best supported by an affirming resolution of the governing body.

Consideration of the Practical Impacts

Once the authority to accept municipal water is found or established, the next inquiry of the board, prior to accepting the municipal water, should be a consideration of the practical impacts of the decision. First, the board must determine whether it has the necessary control over the district facilities to convey the municipal water. Second, the board must consider the how the municipal water will affect operation and maintenance of the facilities. Third, and perhaps most importantly, the District must consider the liability associated with transporting the municipal water and whether transporting the municipal water complies with all federal and state regulations. Finally, the District should consider the financial impacts of acceptance on the district.

Control of Facilities: Easements-In order to discharge the municipal water into the District facilities, the District must have adequate authority over its canals, drains and ditches. Before the District accepts municipal water it should review its easements to ensure adequate control over the facilities.

Generally, the canals and drains of most water delivery districts are located on easements held by the district. Easements may be express and recorded in deed, created by Federal Law or created by State Law. The District should conduct a full title report and history along the entire length of the canal or ditch in which the municipal water will be discharged to ensure it has sufficient control over the canal or ditch.

Often times when a district begins to research its easements it will find they are inadequately or improperly documented. Where the District is unable to determine it has the necessary easement the District may need to take affirmative action to establish an easement. District easements may also arise out of prescription, based on the District's historical use of the canal and ditches. A prescriptive easement is established by use of the land for ten years in an open and notorious manner that is continuous and adverse to the rights of the servient owner. *Nice v. Priday*, 149 Or.App. 667, 945 P.2d 559 (1997), review denied 327 Or. 82, 961 P.2d 216 (1998), citing *Thompson v. Scott*, 270 Or. 542, 546, 528 P.2d 509 (1974).

An easement not readily and adequately documented may be established in a number of ways, including a quiet title suit, a declaratory judgment, negotiation with the deeded land owner, or condemnation. A district requiring assistance in establishing an easement should contact legal counsel.

Even if an adequate easement is established and documented, before the District can accept the municipal water, it must determine if the scope of the easement allows the additional use. The use of an easement is limited to its express terms or historical use. If an added use creates an unreasonable burden on the servient landowner, then the dominant landowner may be liable for trespass or nuisance to the servient landowner.

For example, if the easement has been established specifically or by historical use for the delivery of irrigation water during the irrigation season (generally April to November), then the District may violate the easement by using the canals and ditches for transporting municipal water in the winter. Further, if the municipal use interferes with the District's irrigation purpose, then the District may be liable to the District patrons. If the scope of the easement does not allow the added municipal use, then the District should first negotiate the additional use with the servient landowner.

Given that easements for canals are better described as an "easement in gross", or in other words a right in land that does not benefit one landowner but provides a public purpose providing a benefit to all patrons of the irrigation district, the servient land likely encompasses numerous land entitlements.

Operation and Maintenance: Water Quality and Water Quantity-Before a district may accept municipal water, it must ensure the quality and quantity of the new water will not interfere with the District's primary purpose of delivering irrigation water.

Although many municipalities disagree, it is generally accepted by scientists that municipal water carries a variety of pollutants – including household herbicides, oil, gasoline and other waste. Even treated water has some degree of pollutants present. The District must ensure that the introduction of these pollutants into its canals and ditches does not exceed established concentration standards.

The presence of pollutants in the District's system can result in the loss of endangered fish and other species resulting in penalties under the Endangered Species Act or Clean

Water Act or may simply make the system inadequate to support a good healthy crop or support livestock use. Because the source of such pollutants is difficult to determine, a district often becomes the first, and ultimate, party responsible for pollutants present in its system and under its "control."

In addition, the District must consider the quantity of water that will be discharged in its system. Without question the municipal discharges will increase the amount of water in the District's facilities. The District should consider whether its system can adequately handle a combination of its irrigation diversions, regular drainage and the municipal water. The District should ensure that it has adequate capacity to handle the municipal water without interruption of delivery of the irrigation water and without causing a change in natural or allowed drainage.

The District must also consider the timing of its municipal discharges. Will the municipal discharge interfere with the District's regular maintenance? Generally, districts will complete routine maintenance and repair in the winter months when irrigation diversions are not being made. It is during the winter months that the greatest amount of storm water discharges are commonly made.

The District should also consider whether the increased amount of water will unreasonably burden District staff. Will District staff have to perform additional maintenance activities? Will maintenance be required during more months of the year? Before accepting municipal water the District must consider whether it has sufficient staff and resources to meet the new operation and maintenance demands.

<u>Financial Impacts</u>-The decision to accept municipal water in the District's system can have both positive and adverse financial consequences. First, the major benefit of accepting municipal storm water includes the District's ability to contract with the municipality for the purpose of payment for the use of the District's facilities. The District may contractually arrange for regular (annual or monthly) use payments, as well as payment in kind for maintenance and repair of the canals and ditches. The monies raised contractually by municipal use of the District canals and ditches may be used to fund special projects of the District or pay district debts without additional burden on District members.

On the other hand, the acceptance of municipal water may adversely impact the financial health of the District. First, the increased quantity of water in the District's facilities will necessarily lead to additional maintenance and labor. In considering whether to accept and convey or otherwise manage municipal storm water, the District must consider its labor schedule and determine the fiscal impact of any possible overtime pay incurred by its employees.

The District should consult its insurance policy and determine whether the District's insurance covers liability arising from the acceptance of municipal water. The increased liability associated with accepting and managing municipal water may create insurance issues. The District should confirm its insurance coverage will cover these additional liabilities.

Liability-Potential liability is raised in each of the practical considerations discussed above. Allowing municipal water to be discharged into the District's facilities may expose the District to liability under common law theories or strict liability under federal regulations, such as the Clean Water Act or the Endangered Species Act.

Once the District allows municipal water to enter its canals and ditches it has assumed control over the water under drainage law. In Oregon, the one who diverts water has a duty to prevent water under his control from injuriously flowing onto the lands of another. Likewise, owners of drainage infrastructure have a duty to maintain the associated facilities in good repair so as not to cause injury to others. Unless the water user has a *right* to drain or otherwise back up water onto the land of another, to do so is improper. The resulting water intrusion constitutes either a trespass or "private nuisance" if it is caused due to negligent (or intentional) mismanagement of drainage infrastructure.

Should accepting municipal water cause the quantity of water in the District canals and ditches to flow onto lands or to otherwise change location the District will be liable. The District should explore how the additional water will be contained and controlled to prevent it from overflowing onto adjacent lands and plan for how the additional water will change the volume, quality, and direction of inflow on the lands.

By accepting municipal water the district may also create potential liability for the district under the Federal Clean Water Act ("CWA"). The CWA, 33 U.S.C. Sec. 1251, *et. seq.*, prohibits point source discharges of pollutants into waters of the United States without a National Pollution Discharge Elimination System ("NPDES") permit. CWA Sec. 402. Municipal storm water runoff is classified as a point source requiring an NPDES permit under CWA. CWA Sec. 402. Most water delivery districts and their facilities are exempt from liability under the CWA. Agricultural return flows are exempt from the CWA's permitting requirements so long as discharges are "composed entirely of return flows from irrigated agriculture." CWA Sec. 401(1). When a district allows municipal water to be commingled with the agricultural water the exemption under CWA are likely no longer applicable. It is very possible that the irrigation district in accepting this water now places itself in a position to obtain an NPDES permit for the waters in its canal. If a permit is not obtained, the district has exposure to regulatory civil and criminal liability.

Implementation

If the District decides to allow the use of its facilities for municipal water it should then devise and implement a plan for accepting municipal water in a way that will protect its interests. The District should negotiate a contract with the municipality to accept the municipal water or enter into an intergovernmental agreement with the City. By entering into a contract or an intergovernmental agreement the District can allocate rights, duties, responsibilities, obligations, payments and liability.

Contract-Most special districts have the power to make and enter contracts. A contract with the municipality should address each of the issues and considerations discussed above and allocate liability as appropriate. The agreement may go beyond addressing the acceptance and management of municipal water and may also address other uses of district facilities by the City, including bridges, roads, employees, and provide for safety measures. The contract should also provide for appropriate permitting, reporting and payments to the District for use of the canal and ditches.

Intergovernmental Agreement-An intergovernmental agreement is a written agreement between two or more units of local government for the performance of any or all functions and activities that any of the parties to the agreement is empowered to perform pursuant to its authorizing statute. ORS 190.010 and ORS 190.030. An irrigation district is considered “a unit of local government established to deliver water” pursuant to ORS 190.125(4). The parties form an intergovernmental entity for the purpose of performing the activities or functions detailed in the agreement.

An intergovernmental agreement, while like a contract, offers the District broader management authority and power than a contract would. It would also secure very distinct division of responsibilities and liabilities between the District and the City because an intergovernmental agreement automatically recognizes the underlying entities’ statutory authorities and duties.

ORS 190 specifically anticipates that organizations established to deliver water, including irrigation districts, may enter into such agreements to deliver water under a joint board of control. ORS 190.125. A joint board of control created by an intergovernmental agreement may undertake cooperative activities, such as (1) sharing personnel; (2) entering into contracts for operation; (3) sharing use of equipment and facilities; and (4) other cooperative activities authorized. The joint board of control would be composed of the directors and managers of both the District and the City.

CONCLUSION

The decision of a special district organized to deliver irrigation water to accept and transmit municipal water is a fact specific inquiry. The purpose of this paper is not to provide an affirmative answer as to whether a district should or should not accept municipal water. Instead the purpose is to help district managers and governing bodies indentify and analyze the various issues that should be considered prior to accepting municipal water. A district’s decision should be made only after full consideration of the legal and practical issues that may arise. A district must determine that it has the legal authority to accept the municipal water and that accepting the municipal water will not interrupt or impair operations of the district. The district must also consider its potential liability. Finally, a district must limit its potential liability and maximize the potential benefits by implementing a plan for accepting the municipal water via contract and an intergovernmental agreement.

CASE STUDY — THE TRUCKEE CANAL: A TRANSBASIN DIVERSION FROM THE TRUCKEE RIVER BASIN TO THE CARSON RIVER BASIN

Joseph I. Burns[1]
Michael C. Archer[2]

ABSTRACT

The Truckee Canal, which diverts water from the Truckee River basin to the Carson River basin in Nevada, was constructed in 1905 by the Reclamation Service as a part of the Truckee-Carson Project. The Reclamation Service was the predecessor of today's United States Bureau of Reclamation. The development of a water supply for the Truckee-Carson Project and the operation of the Truckee River system and the Truckee Canal have resulted in almost one hundred years of controversy and litigation.

The Truckee-Carson Project was one of the first projects authorized by the United States government under the 1902 Reclamation Act. At the time of authorization, it was envisioned that 300,000 acres of desert land could be brought under irrigation with the water supply coming from both the Truckee and Carson Rivers. The attempt to develop a water supply for the Truckee-Carson Project and to satisfy the water rights of users upstream of the Truckee Canal diversion has been extremely controversial. Both of the rivers originate in California and flow into Nevada, introducing interstate issues. To further complicate matters, the Truckee River terminates in Pyramid Lake, the home of the Cui-Ui sucker fish, a federally listed endangered species. Pyramid Lake is fully contained within the Pyramid Lake Paiute Indian Reservation. The Truckee River is the primary water supply source for the cities of Reno and Sparks, two rapidly growing cities.

This case study traces the actions taken in the Truckee River basin to meet the Project demand and the resulting impacts on the entire Truckee River system. The demands placed on the Truckee River system have resulted in one of the most litigated and complex operations of any river system in the United States.

This paper was originally presented by the authors at the 2001 USCID Water Management Conference, Transbasin Water Transfers, June 27-30, 2001, in Denver, Colorado. The original paper is provided below followed by a brief discussion of what has occurred since 2001. An updated version of Figure 2, Historical Pyramid Lake Water Surface Elevation, is also included at the end of the report.

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INTRODUCTION

The Truckee Canal, completed in 1905, diverts water from the Truckee River basin to the neighboring Carson River basin in the State of Nevada as shown in Figure 1. The Truckee Canal is part of the Truckee-Carson Project, one of the first projects constructed by the United States Reclamation Service[3], and has spawned nearly 100 years of litigation, water rights challenges, interstate interaction, endangered species challenges, Indian water rights claims, and congressional involvement on the Truckee and Carson Rivers. In 1990, the Truckee-Carson-Pyramid Lake Water Settlement Act (Settlement Act) was passed by the United States Congress to “resolve” the many Truckee-Carson interbasin and California-Nevada interstate issues. The Settlement Act is still in the implementation phase and appears to be several years away from finalization.

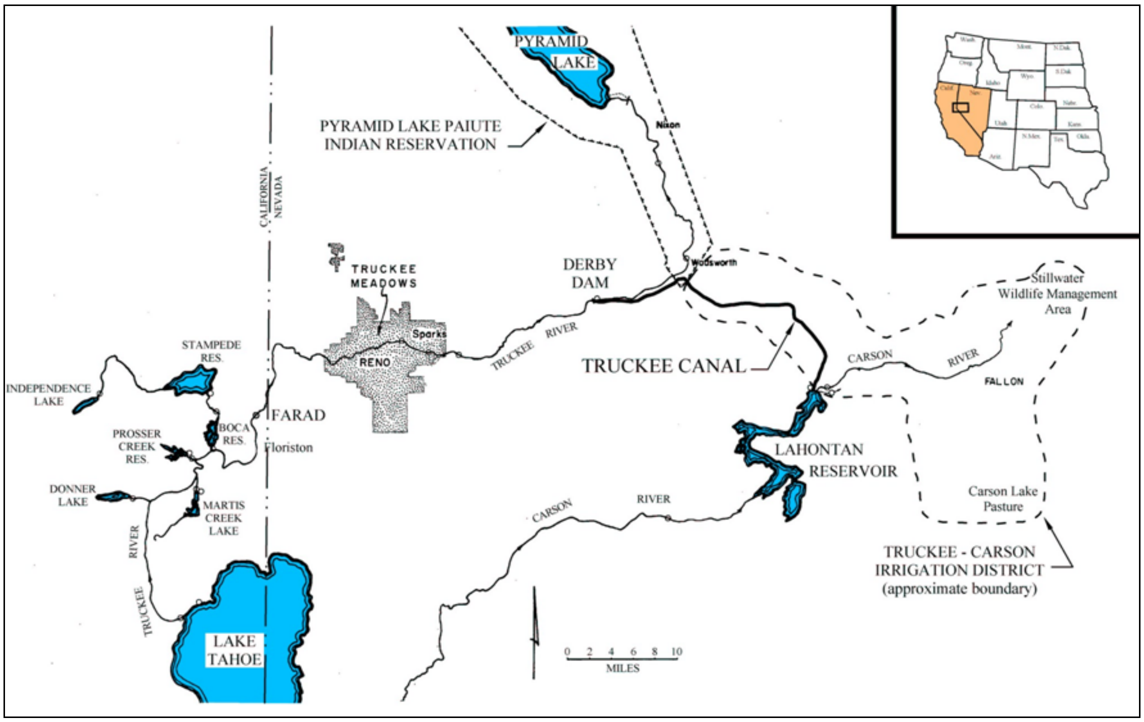

Figure 1. Location Map

The Truckee River originates at Lake Tahoe in California and flows northeasterly to the California-Nevada border and continues to its terminus in Pyramid Lake, which is fully contained within the reservation of the Pyramid Lake Paiute Tribe. The Carson River originates in California on the eastern slope of the Sierra Nevada south of Lake Tahoe and flows northeasterly to its terminus in the Carson Sink. The Truckee Canal diverts water from the Truckee River at Derby Dam just upstream from the Pyramid Lake Paiute Indian Reservation and delivers that water to adjacent lands and to the Lahontan Reservoir on the Carson River.

The diversion from the Truckee River was one element in a complicated and ongoing

[3] In 1923 the Reclamation Service became the United States Bureau of Reclamation.

saga involving the Truckee River in California and Nevada and the Carson River in Nevada.. This case study outlines the historical sequence of events that has resulted in the Truckee River being perhaps the most litigated, contentious and complex water challenge in the United States.

THE TRUCKEE-CARSON PROJECT

The Federal Reclamation Act of 1902 authorized the withdrawal of public lands in Nevada for the Truckee-Carson Project (Project). The Project was subsequently renamed the Newlands Project. In 1902 it was envisioned that an additional 300,000 acres of desert land could be irrigated by the waters of the Truckee and Carson Rivers. However, as of today, the Project, operated by the Truckee-Carson Irrigation District (TCID), has only 73,700 acres of water righted lands of which approximately 65,000 acres have been irrigated. Water is delivered directly from the Truckee Canal in the Truckee Division of the TCID and from Lahontan Dam and the Carson River in the Carson Division of the TCID. The Project has about 326 miles of canals. The Fallon Paiute-Shosone Indian Reservation near Fallon contains about 8,000 acres and is supplied irrigation water from the Project. The Carson River and tail-water from the Carson Division flow into two wetland areas: Carson Lake Pasture and the Stillwater Wildlife Management Area.

When the Project was authorized, Reclamation Service engineers recognized that stored water in Lake Tahoe would be required for the Project. The upper seven feet of Lake Tahoe was regulated by a log crib dam at its outlet to the Truckee River, creating over 800,000 acre-feet of usable storage. The dam was owned and operated by the Donner Boom and Logging Company primarily for regulating the flow of the Truckee River to transport logs to downstream saw mills. In 1903 the Reclamation Service posted a notice at the dam claiming a right to store and release 3,000 cubic feet per second (cfs) from Lake Tahoe. In an effort to secure control of the outlet from Lake Tahoe, Reclamation Service purchased 64 acres of land south of the existing dam and in 1905 awarded a contract for the construction of new outlet works. Subsequent litigation by the owners of the dam and others resulted in the cancellation of the construction contract.

In 1905 the Reclamation Service completed the Truckee River Diversion Dam (Derby Dam) and the Truckee Canal to transport Truckee River water 31 miles to the Carson River. In 1915, the 162 foot high Lahontan Dam, which forms the 317,000 acre foot Lahontan Reservoir, was completed at the terminus of the Truckee Canal on the Carson River. The Canal has a capacity of 900 cfs but the Project has the right to discharge from Lake Tahoe an amount of water sufficient to deliver to the head of the Canal, after transportation losses, 1,500 cfs.

LITIGATION AND NEGOTIATION

Without the benefit of stored water, the Project farmers were struggling to survive with an inadequate water supply. In 1908, the Truckee River General Electric Company (TRGEC) purchased the Lake Tahoe Dam and the adjacent 14 acres from the Floriston Land and Power Company and Floriston Pulp and Paper Company. The TRGEC was the predecessor of the current Sierra Pacific Power Company (SPPCo), the current purveyor of water in the Reno-Sparks metropolitan area[4]. In 1909, the Reclamation Service and the TRGEC jointly initiated reconstruction of the dam and by 1913 the dam, which is in place today, was completed. The dam regulates 6.1 feet of water in Lake Tahoe providing 720,000 acre feet of storage. In the 1908 purchase agreement, the TRGEC agreed to release stored water to maintain Truckee River flows of either 500 cfs or 400 cfs, depending on the time of year, as measured at the Farad Gage near Floriston at the California-Nevada state line. This flow requirement is referred to as the Floriston Rates. The Floriston Rates flow provided power for the pulp and paper company and water for four run-of-the-river power plants owned by the TRGEC. The Floriston Rates requirement also ensured water would be released for downstream uses and became the cornerstone and the key to potentially settling Truckee River water problems almost 100 years later.

Unable to consummate an operating agreement for the Lake Tahoe dam, the Reclamation Service took two significant steps to ensure a water supply for the Project. In 1913, the United States brought an action in federal court (The United States of America vs. Orr Water Ditch Company, et al.) to adjudicate the upstream water rights in Nevada in order to protect the Project's water rights with a priority of 1902. This action was not completed, as will be discussed later, until 1983. The other significant step was taken in 1915 when the United States brought a condemnation suit (United States of America vs. The Truckee River General Electric Company (TTRGEC)) for control of the Lake Tahoe Dam. The suit resulted in a stipulated decree that granted the United States an easement to use the outlet controlling works and the adjacent 14 acres at a cost of $139,500. In this stipulated decree, the United States agreed to meet the aforementioned Floriston Rates requirement. TTRGEC retained ownership of the dam and surrounding land.

In the Orr Water Ditch Company adjudication, a Special Master for the federal court submitted his findings as to the owners of Truckee River water rights in Nevada which were approved by the Court in a "Temporary Restraining Order" in February 1926. At this time, the United States transferred the care, operation and maintenance of Lake Tahoe Dam to the Truckee-Carson Irrigation District. Although the Restraining Order dealt only with water rights in Nevada, there was concern by Lake Tahoe shore owners about how Lake Tahoe was to be operated, primarily in regards to high water levels. The problems between the States and the federal government were compounded by a severe drought in the early 1930s which lowered the level of Lake Tahoe below its natural rim resulting in limited water supplies for all Truckee River water right holders, including the Project, and severely limiting boating access to piers in Lake Tahoe.

After years of negotiations, the United States, TCID, Washoe County Water Conservation District (Reno-Sparks area), SPPCo and "Other Users of the Waters of the Truckee River" signed the Truckee River Agreement in June 1935. This was in effect an operating agreement, although not signed by California interests, which provided for

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[4] Sierra Pacific Power Company's interest as purveyor of municipal water in Nevada has been purchased by the Cities of Reno and Sparks and Washoe County and will be managed by the Truckee Meadows Water Authority.

stabilizing the mean elevation and limiting the maximum elevation of Lake Tahoe, provided for additional storage facilities to benefit the Washoe County Water Conservation District, reduced the flow of winter draft from Lake Tahoe, and served as the basis for entering a final decree in the Truckee River Adjudication suit. The Agreement required that a storage facility of at least 40,000 acre-feet be constructed and operated in conformance with this agreement before a final decree could be entered. Boca Reservoir with a capacity of 40,800 acre feet was completed in 1937 and the final decree was entered in 1944. The final decree was challenged by the Pyramid Lake Paiute Tribe in 1975 (United States of America and Pyramid Lake Paiute Tribe of Indians vs. Truckee-Carson Irrigation District, et al.) but the decree was upheld in 1983 by the United States Supreme Court. The Orr Ditch Decree allocated 30,000 acre feet of water for irrigation on the Pyramid Lake Indian Reservation but allocated no water to sustain the fishery or level of Pyramid Lake.

Throughout these years, the maximum amount of water possible was being diverted from the Truckee River at Derby Dam, not only for irrigation in the Project but also for single purpose power generation in Project facilities. These diversions had disastrous effects on Pyramid Lake as is shown on Figure 2. By the 1940s the lake level had dropped 60 feet and the world famous Lahontan Cutthroat Trout became extinct due to a combination of overfishing and the inability of the fish to migrate upstream to spawn. In 1970, the Cui-Ui, a sucker fish found only in Pyramid Lake and a cultural centerpiece to the Pyramid Lake Paiute Tribe, was designated an endangered species. A reintroduced strain of Lahontan Cutthroat Trout in Pyramid Lake has been listed as a threatened species.

If the water supply for Nevada interests, including the Project, was to be protected, it was imperative that California and Nevada reach agreement on the division of water in Lake Tahoe and the Truckee River Basin. The two states initiated negotiations in the 1950s to develop a compact on the division of the water. By 1970, after 15 years of negotiations, the two state legislatures approved the compact; however, the United States Congress refused to ratify the bi-state agreement because of objections by the Pyramid Lake Paiute Tribe.

As the Pyramid Lake level continued to drop, litigation increased. In November 1972, and supplemented in 1973, the United States District Court, District of Columbia issued a ruling in Pyramid Lake Paiute Tribe of Indians vs. Rogers C. B. Morton, Secretary of the Interior finding that the Operating Criteria and Procedures (OCAP) for the Truckee and Carson Rivers, which would permit the diversion of 378,000 acre feet of water from the Truckee River at Derby Dam, were arbitrary and not based on the sound exercise of discretion. As a result of this ruling, the diversion in 1974 was not to exceed 288,000 acre feet. Additionally, detailed criteria defining when and how much water could be diverted were spelled out, checks on individual water rights were required, and actions to minimize waste were to be implemented. This action resulted in additional litigation when TCID, which was not a party in the aforementioned action, did not reduce their diversions or implement the court's order resulting in a 1979 order by the court for TCID to "repay" 1,050,000 acre feet to Pyramid Lake. As of this date, the repayment has not been initiated.

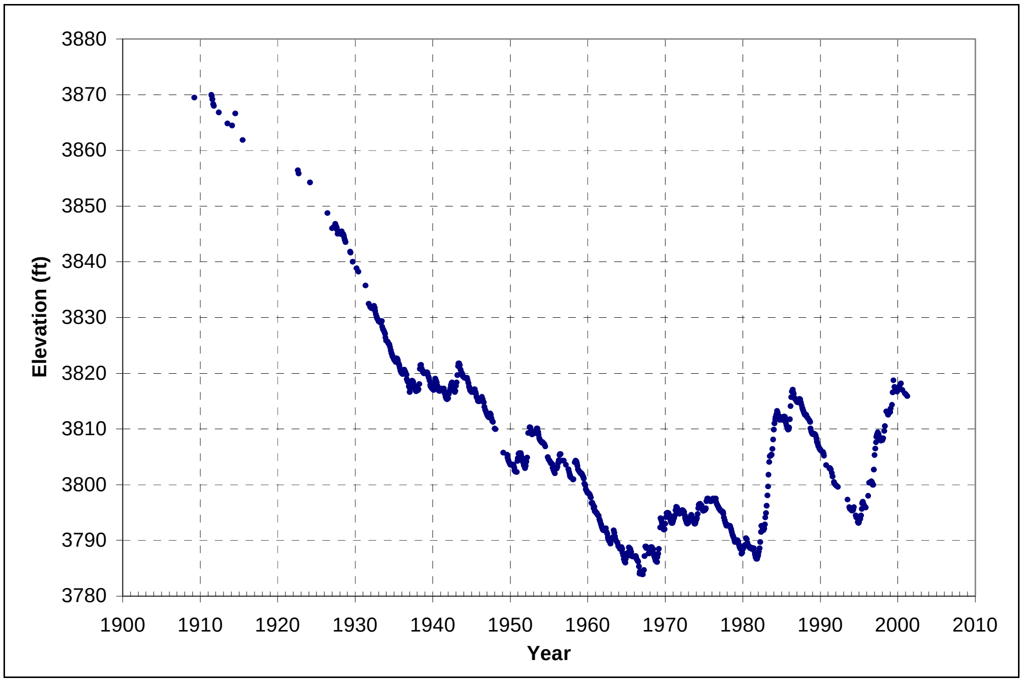


Figure 2. Historical Pyramid Lake Water Surface Elevation

The enactment of the Endangered Species Act in 1969, the need to develop a secure water supply for the rapidly growing Reno-Sparks metropolitan area, litigation involving water quality issues, pressure to reduce the dependency of the Project on the Truckee River, and the imperative that California and Nevada reach a Congressionally approved bi-state agreement on the division of waters of Lake Tahoe and the Truckee River, came together with new urgency in the 1970s. Negotiations among the stakeholders resulted in failed attempts to get federal legislation to solve this myriad of outstanding problems.

A breakthrough in solving the impasse came when the President of SPPCo and the Chairman of the Pyramid Lake Paiute Tribe, met in 1988 and concluded that they held the key to providing a basis for settlement of these many issues. The key was the Floriston Rates. SPPCo would agree to forego the requirement that Floriston Rate flows be met at the run-of-the-river power generation plants when all the water was not needed by downstream water right holders. If the water saved by reducing Floriston Rates flow could be held back in upstream reservoirs, it could be stored as an emergency drought supply for the Reno-Sparks metropolitan area. Water stored in excess of the metropolitan area drought needs could be made available for release for fishery purposes when that water would be most beneficial for the endangered and threatened fish in Pyramid Lake. This concept was developed and incorporated into a Preliminary Settlement Agreement signed by Pyramid Lake Paiute Tribe and SPPCo in 1989.

Using the Preliminary Settlement Agreement as a foundation, California, Nevada, the United States, SPPCo, Pyramid Lake Paiute Tribe, Fallon Paiute Shoshone Indian Tribe and TCID, under the sponsorship of Nevada's United States Senator Harry Reid, developed the Negotiated Settlement Act which was adopted into law in 1990 in Public

Law 101-618.

The Settlement Act apportions the waters of Lake Tahoe and the Truckee River between California and Nevada; authorizes the coordinated operation of all Truckee Basin Reservoirs and Lake Tahoe to enhance fish and wildlife, recreation and water supply benefits; authorizes the acquisition of water rights for additional water supply to wetlands and wildlife management areas; settles long standing litigation and claims between the stakeholders; provides funds to fulfill the Federal trust obligations to Indian tribes; fulfills the goals of the Endangered Species Act by promoting the enhancement and recovery of the endangered Cui-Ui and threatened Lahontan Cutthroat Trout; and protects significant wetlands from further degradation and enhances the habitat of many species of wildlife which depend on those wetlands.

Today diversion from the Truckee River, limited by the current OCAP and by acquisition of agricultural water rights for use in instream flow enhancement and for water quality improvement and protection of the endangered species, has resulted in reversing the decline in Pyramid Lake levels. With a repeat of the hydrology of the last 100 years and the implementation of the Negotiated Settlement, it is estimated that Pyramid Lake will rise over 60 feet.

To implement the Settlement Act, a Truckee River Operating Agreement (TROA) was to be negotiated for the operation of the Truckee River System. Although the Settlement Act was specific in many areas, the very detailed operating criteria required to carry out the mandate to coordinate the operation of all the Truckee River Reservoirs, to protect the existing water right holders and to meet newly defined environmental objectives, has resulted in eleven years of negotiations. These eleven years have demonstrated the axiom that the "devil is in the details". It is anticipated, or hoped, that the TROA will be signed this year and that the environmental documentation will be completed in two years. Subsequently, federal courts in Nevada and California will have to approve required modifications to the Orr Ditch Decree and the 1915 Lake Tahoe Decree.

CONCLUSION

It will have been just over 100 years since the Truckee River transbasin diversion was implemented that the repercussions of that diversion may yet be "settled". However, that is dependent on the TROA being completed and signed by all necessary parties. If not, the litigation and/or negotiations may still go on - for another 100 years? Perhaps.

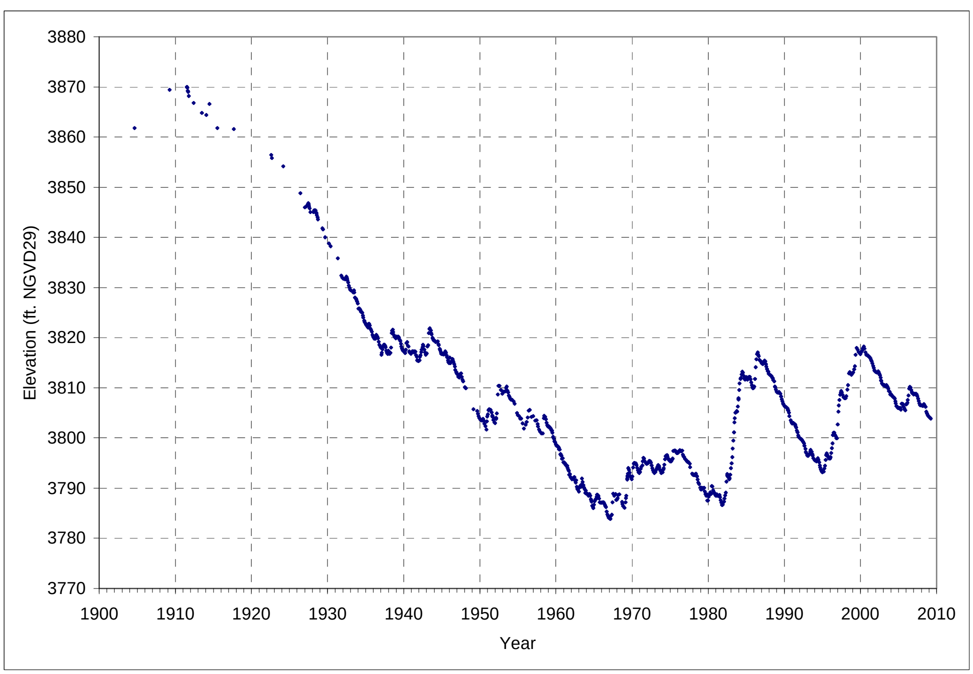
UPDATE 2001-2009

In 2001, the authors stated in the foregoing paper: "It is anticipated, or hoped, that the TROA will be signed this year and the environmental documentation will be completed in two years." It was also noted that the "devil is in the details." It took an additional eight years for the mandatory signatory parties to "meet the devil" and reach unanimous agreement on an operating agreement.

The Truckee River Operating Agreement (TROA) was completed in January 2008 by the mandatory signatory parties: United States, State of California, State of Nevada, Pyramid Lake Paiute Tribe of Indians and Truckee Meadows Water Authority. (Truckee Meadows Water Authority took over delivery of municipal water in the Truckee Meadows area from Sierra Pacific Power Company in 2001). TROA is the preferred alternative analyzed in the Final Environmental Impact Statement/Environmental Impact Report, Truckee River Operating Agreement, January 2008. TROA was signed in Reno, Nevada on September 6, 2008 by the mandatory signatory parties and eleven additional signatory parties: City of Reno, County of Washoe, City of Sparks, City of Fernley, Washoe County Water Conservation District, Carson-Truckee Water Conservancy District, Sierra Valley Mutual Water Company, Truckee Donner Public Utility District, North Tahoe Public Utility District, Placer County Water Agency and Sierra Pacific Power Company. Senator Harry Reid signed the Agreement as a witness.

A number of prerequisites must be satisfied before TROA becomes effective. Among the prerequisites, TROA must be submitted to the U. S. District Courts which administer the Orr Ditch Decree and Truckee River General Electric Decree for approval of any necessary modifications in the provisions of these Decrees. In March of 2009 the Nevada U. S. District Court approved modifications of the Truckee River General Electric Decree incorporated into TROA. Petitions to make necessary changes to water rights in California and Nevada to accommodate flexible Truckee River operations set forth in TROA have been submitted to the California Water Resources Control Board and the Nevada State Engineer, respectively.

TCID has initiated repayment of water to Pyramid Lake ordered by the court in 1979.



Updated Figure 2. Historical Pyramid Lake Water Surface Elevation

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COLORADO'S GRANT PROGRAM TO EXPLORE ALTERNATIVE AGRICULTURAL WATER TRANSFER METHODS

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Matt Lindburg, P.E.[2]

ABSTRACT

Rapid population growth, urbanization and increased competition for water have created significant pressures on certain agricultural sectors of Colorado's economy. Conservative estimates indicate that Colorado could lose almost 500,000 irrigated acres by the year 2030 as water is transferred out of agriculture and into municipal and industrial uses. A major portion of those acres will likely be lost in the Arkansas and South Platte basins. To better understand and to help address this trend, the Colorado Water Conservation Board (CWCB) authorized staff to further investigate alternatives to traditional purchase and transfer of water from irrigated lands to new uses. In addition, the 2007 Colorado legislature authorized the CWCB to develop a grant program to facilitate the development and implementation of alternative agricultural water transfer methods.

The CWCB has awarded $1.5 million in grants to water and sanitation districts, irrigation companies, water conservancy districts, and other organizations to study alternative water transfer methods. Projects include field research on deficit irrigation and quantification of consumptive use savings; research regarding establishment of water banks; research on new institutional and legal mechanisms to facilitate alternative water transfers; and creation of tools to help agricultural producers and others to evaluate the economic feasibility of alternative water transfers.

The Colorado Corn Growers Association, Ducks Unlimited, and The City of Aurora, Colorado were awarded funding for a project that includes development of practical guidance for agricultural producers and others for implementation of alternative water transfer methods. The guidance, along with other data and information, will be used and tested in the development of three wetland/alluvial aquifer recharge projects. The water supplies for the wetlands will be obtained from alternative water transfers. The water that is recharged to the alluvial aquifer from the wetlands will eventually reach the South Platte River and will be available for use by municipalities or industry.

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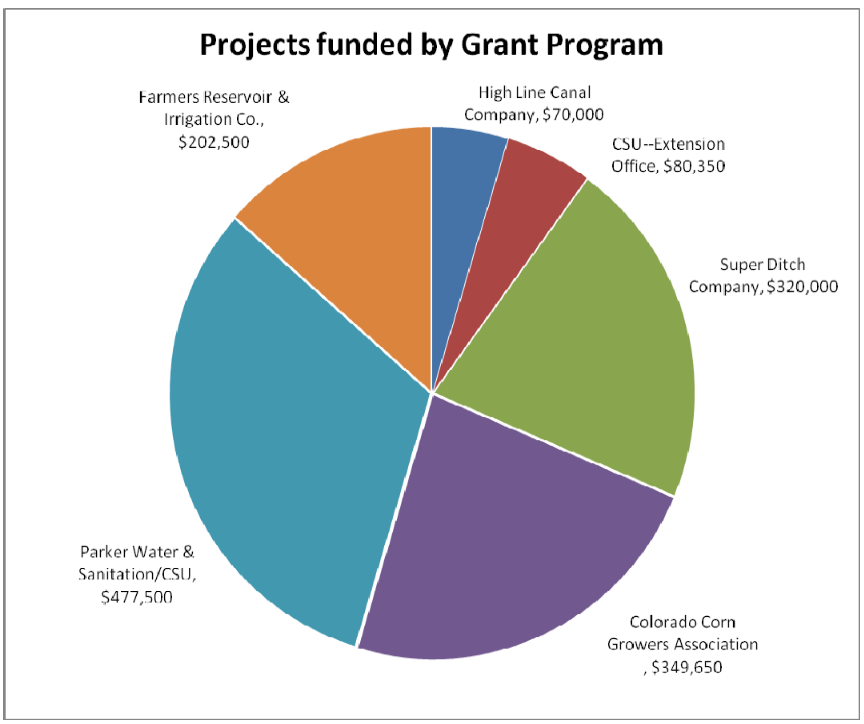
INTRODUCTION

Agriculture in the Arkansas and South Platte River basins in Colorado is being pressured by urbanization, rapid population growth, and increased competition for water. As in many semi-arid areas in the western United States, senior water rights are held by agricultural interests. Metropolitan water providers in Colorado's Front Range region have acquired agricultural water rights in an effort to provide reliable supplies to their customers. Acquisition of agricultural water rights in Colorado, however, results in the permanent dry-up of formerly irrigated lands. The trend in dry-up is predicted to continue. **Estimates suggest that Colorado could see dry-up of almost 500,000 irrigated acres by the year 2030 as water is transferred out of agriculture and into municipal and industrial uses.** In fact, the loss of irrigated acres could be even greater than current estimates if future available supplies are less than projected.

In 2007, the Colorado state legislature authorized the Colorado Water Conservation Board (CWCB) to initiate a grant program with the objectives of better understanding and promoting alternative means of transferring water from agriculture to other uses. The legislature appropriated $1.5 million to the grant program with the intent of facilitating and promoting alternative water transfers. Alternative means of transferring water include, but are not limited to, rotational fallowing, interruptible supply agreements, water banking, alternative cropping and deficit irrigation practices.



It should be noted that there are other factors that are impacting the Colorado agricultural economy besides water transfers. Financial, economic, and demographic trends have been negatively impacting the agricultural economy as well. The program will not specifically address these issues. However, it is very possible that the results of the grant program will create alternatives for agricultural producers that could ease the negative impacts of financial and economic trends.

It should also be noted that agricultural water rights in Colorado are a property right. The grant program does not seek to interfere with or criticize those who would exercise their option to sell their water rights. The CWCB acknowledges that this program will not and cannot end permanent transfers of water from agriculture to other uses. For agricultural producers, permanent transfers may be their best business decision. However, there is a growing interest in other means of transferring water that do not include permanent dry-up. The CWCB would like to encourage the development of knowledge regarding alternative transfers and to do what it can to further the establishment of these alternatives.

Grants under this program were awarded on a competitive basis. Projects receiving funding under this program need to not only provide for the facilitation of a water transfer, but must also provide transferable knowledge and information that can be used by water interests on a statewide basis. Grant applicants need to provide at least 10% of the cash necessary to complete the project. In addition, the grant monies cannot be spent for design or construction of projects or for Colorado Water Court proceedings.

Several projects have been initiated using the grant funds made available by the CWCB. The CWCB accepted grant applications on March 31 and September 30, 2008. All of the available funding under the program was distributed. This paper describes most of the projects receiving funding. The objective of this paper is to describe the projects that are currently under way so that readers with an interest in alternative agricultural water transfers can gain additional knowledge or make contact with grant recipients to obtain further details on the projects.

Table 1. Description Projects Yields, Terms and Expected Lease Prices

Projects/Activity	**Expected Yield (AF)**	**Terms of Lease**	**Lease Price (AF/year)**
FRICO	10,000	Variable	\$300 to \$600?
Parker WSD/CSU	20,000 to 40,000	Variable	\$300 to \$600?
Super Ditch	15,000 (dry year) to 45,000 (wet year)	Fixed (40 year) and Variable	\$400 to \$600?
Highline Canal Co.	TBD	Fixed and Variable	\$300 to \$600?
CSU Extension	N/A	N/A	TBD
Colorado Corn Growers Assoc.	TBD	Fixed and Variable	\$300 to \$600?

DESCRIPTION OF PROJECTS FUNDED UNDER THE GRANT PROGRAM

Many of the projects funded under the CWCB grant program are described below. For further information, contact Mr. Todd Doherty at the Colorado Water Conservation Board.

Farmers Reservoir and Irrigation Company Water Bank

The Farmers Reservoir and Irrigation Company (FRICO) is the largest irrigation company near the Denver metropolitan area. FRICO has initiated a project to evaluate the potential effectiveness of a variety of alternative transfer methods including rotational fallowing, interruptible supply agreements, lease back agreements, and changes in cropping patterns. The objective of these methods is to reduce consumptive use for purposes of transferring the "saved" consumptive use to municipal or industrial users. In addition, an innovative "shared" water bank concept shall be tested to optimize the physical, economic, and administrative structure needed to capture, store, and transfer water to purchasers in the Denver metropolitan area.

The "shared" water bank concept to be developed in this project will use existing FRICO infrastructure and recharge capabilities to capture and store unused agricultural and municipal/industrial consumptive use that is available in relatively wet years. The resulting water would then be available to be used by agriculture and municipal/industrial users. The bank will be managed and administered by FRICO.

The shared water bank concept in this project will allow for both intra and inter year banking opportunities. The potential for these opportunities exist due to FRICO's infrastructure and recharge capabilities. In addition, a great deal of information has been developed about the FRICO system. Engineering studies currently underway to identify consumptive use, recharge capabilities, and the timing of return flows will provide much needed technical information that is not typically available on irrigation delivery systems in Colorado.

Several benefits are anticipated from this project. These benefits are described below:

- Municipal and industrial users can firm up existing supplies without additional investments in infrastructure and without having to transfer additional supplies from current agricultural users.
- FRICO shareholders would receive a portion of the water in exchange for the use of infrastructure.
- FRICO and other agricultural groundwater users will benefit from having access to a relatively inexpensive source of recharge to the alluvial aquifer, which will help offset their potential streamflow depletions from the consumption of irrigation water provided by wells.
- Environmental benefits will likely result from this project including improved stream flow conditions resulting from alluvial aquifer recharge and the creation of wetlands at the recharge and discharge sites.

- Water users outside the project area may benefit from the study of the legal, financial, and institutional requirements and operations of a water bank.
- While specific yields and costs are to be determined by the study, it is estimated that approximately 10,000 acre-feet could be captured making available 5,000 AF for the agricultural users and 5,000 AF for the participating municipalities. It is anticipated that FRICO and the municipalities would enter into a short-term contract (i.e. two-year) to pilot the project. The costs could range anywhere from $10,000 to $25,000 per acre-foot or $300 to $600 AF/year.

Lower South Platte River Demonstration Project

The Parker Water and Sanitation District (PWSD) and Colorado State University (CSU) have teamed to conduct a project to explore means of reducing consumptive use of agricultural crops using deficit irrigation. The project will include a four-year study of the response of crops to various levels of irrigation and demonstration projects.

The proposed four-year project scope was developed by CSU and will be implemented by several of the agriculture-related departments at CSU. Mr. Frank Jaeger, District Manager at PWSD, will be the overall project manager and Mr. Bruce Lytle of Lytle Water Solutions will serve as the project liaison, coordinating water rights issues associated with the proposed research. In addition an Advisory Committee was established to assist in the project. The Advisory Committee will meet periodically throughout the course of the project and includes local farmers, business representatives, State Engineer representative and the Northern Colorado Water Conservancy District.

The project will include controlled research by CSU on a farm in Logan County, Colorado that is owned by PWSD. Various crops will be planted by CSU and these plots will be irrigated in different patterns to assess the crop's ability to thrive under varying irrigation practices, e.g., irrigating alfalfa prior to its first cutting, letting it grow without irrigation through the second cutting, and then irrigating it again prior to the third cutting. In this way, CSU will develop a database on the most efficient irrigation practices for various crops where the crop can still thrive under a lower irrigation volume. The difference between the reduced irrigation volume and the historic irrigation volume related to consumptive use could then be made available for transfer to PWSD for municipal use. A series of ground water monitoring wells has been developed around the research farms to better understand ground water levels and the potential for sub-irrigation. Participation by State Engineer's Office will be critical to answering questions regarding the quantification of consumptive use that will be removed from the land while the land is still being irrigated and successfully administering a water transfer done in this way.

While the controlled research on the PWSD farm will develop an extensive database on deficit irrigation practices, it is also necessary that these applications be implementable by agricultural producers on a farm-scale basis. To this end, there are also three on-farm demonstrations at PWSD's other farms in Logan County, which will have the farmers continue to work their farms with guidance from CSU. In this way, CSU will receive valuable input and feedback from the farmers about techniques that can work on a farm-scale basis. The challenge of this research is to not only develop implementable techniques for farmers, but also to measure understanding by the farmers that these techniques can still provide them with an economic use of their land.

It is estimated that the project could yield between 20,000 to 40,000 acre-feet. CSU has completed a survey of farmers in the lower South Platte River valley and found that approximately 60 percent of the respondents were willing to lease their water rights at values mostly in the range of $300 to $500 per AF/year.

The Super Ditch Company

The objective of this project is to conduct further research regarding the establishment of the Super Ditch Company. The Lower Arkansas Valley Water Conservancy District has driven the establishment of the Super Ditch Company. The company is envisioned as an independent, institutional and legal entity that will facilitate leases of water to municipal or other users from irrigators who voluntarily forego irrigation. It is anticipated that the primary means for foregoing irrigation will be through rotational fallowing.

The water leases may take various forms, including long term leases, interruptible water supply agreements, and water banking. Water leases will be for specific terms of years and binding upon both the municipal water user-lessees and the irrigator-lessors. The leases will be a legal obligation to the ditch company participating and constitute a continuing obligation of the owner of the ditch shares. In this manner, the leases will provide certainty to the municipal/water user lessees. There will be a variety of lease terms necessary to meet the differing needs of lessees, but it is expected that leases will run for as long as 40 years with a right of renewal. Municipalities have demonstrated their comfort with such lease periods through contracts with the Bureau of Reclamation.

There is enough water available from the participating ditches to provide approximately 15,000 acre-feet of year for lease in a dry year, approximately 30,000 acre-feet in an average year, and approximately 45,000 acre-feet in a wet year. These lease yields conservatively assume a 65% participation rate by irrigators, and a 25% fallowing rate, which are well below expected participation and fallowing rates. It is estimated that irrigators would willing to accept a lease payment of $400 to $600 AF/year.

Highline Canal Company Investigation of Alternative Water Transfers

The Highline Canal Company is conducting a project to explore implementation of various means of alternative water transfer including interruptible water supply agreements, long-term land fallowing, spot market leases (for use during drought), and water banking. Water developed under these methods will be provided to other users via existing irrigation infrastructure or via a proposed pipeline. The project includes engineering studies to determine the amount of water that could be transferred and the location, timing, and volume of historical irrigation return flows that would need to be maintained in order to prevent injury to downstream water users. Water made available will be leased to other water users.

Economic and Operational Costs of Fallowing

The CSU Extension Office is evaluating technical (i.e., economic, biophysical, and management) issues involved in maintaining or improving yields on fallowed lands when they are put back into production after a lease arrangement ends. In addition, this project will provide a logistical analysis regarding the practicability of coordinating these arrangements with a broker (likely the Super Ditch Company), and also canal companies possessing both senior and junior water rights in the Arkansas River Valley.

Leasing water saved from rotational fallowing, interruptible supply agreements, etc. are common vehicles for temporarily transferring water from agriculture to other uses. However, farmers who are unfamiliar with the concept raise key questions about:

- The extent to which this strategy can help sustain farming operations economically
- The biophysical impacts (e.g., soil quality) on farmland during fallowing, and how these impacts may affect future crop yields
- The required costs and management associated with bringing land back into production after it has been fallowed

These questions must be answered to inform irrigators of the lease value of their water rights. Actual and ongoing demonstrations of water transfer will be included with this project and are intended to address the information gap regarding the economic value and practicality of water leasing. In addition, the results of these demonstrations will allow CSU Extension to provide recommendations on land fallowing and returning fallowed land back to production.

Project to Develop Practical Alternative Agricultural Water Transfers

The Colorado Corn Growers Association (CCGA), Ducks Unlimited (DU), and the City of Aurora (Aurora) proposed and were awarded a project to develop practical alternatives for water transfers that will help maintain economically sustainable irrigated agriculture in Colorado. The objective of the project is to provide alternative means of transferring water from agricultural uses to municipalities and industry that maintain agricultural ownership of the water and that sustain the irrigated status of the farm ground. The end result of these types of transfers would be a reduction in permanent dry-up of irrigated ground and the local economic impacts associated with dry-up. Assisting in the research for this project are the Colorado Water Resources Research Institute (research engineers and economists from Colorado State University); Lind, Lawrence, and Ottenhoff, LLC (attorneys); and Brown and Caldwell (engineers and economists).

As the above objectives imply, the primary focus of this project will be to examine other means of providing water that are alternatives to “buy and dry” and that maintain sustainable irrigated agriculture. The Colorado Corn Growers Team (“Team”) proposes to accomplish the objective by rigorously investigating and developing five alternative transfer methods for application to three specific projects in the South Platte Basin and by creating a Business Plan that can be used by agricultural producers, municipalities, industry, etc. to evaluate and to implement alternative agricultural water transfers in the South Platte River basin and across Colorado. This Business Plan will be tested and validated through application of three proposed alternative water transfers as part of this project and will draw on the practical experience gained from other water transfer projects completed by members of the Team. This Business Plan will:

- Allow agricultural producers to evaluate various alternative means of transferring a portion of their water while maintaining a sustainable farming practice
- Facilitate the practical implementation of alternative water transfers by agricultural producers in transfers of water to municipal and other users
- Extend practical utilization of sustainable alternative agricultural water transfers throughout the state

The Team seeks to promote the practical utilization of alternative agricultural water transfer methods in Colorado by building on the work completed by the Statewide Water Supply Initiative, DU's experience in the use of agricultural water rights for the development of wetlands and wildlife habitat, Aurora's experience in transfers and leases of agricultural water for municipal and industrial purposes, and the experience and research conducted by other team members including the Colorado Water Resources Research Institute concerning alternative agricultural water transfer measures. In addition, the Team also seeks to compliment or to enhance the work done by other recipients of these grant funds. During the course of the project, the Team will work closely with the CWCB to identify ways that other work under this program can be incorporated into this project.

As noted above, the Business Plan will be tested on three alternative water transfer projects. The projects will be three constructed wetlands in the South Platte River basin in Colorado. The water supply for the wetlands will be supplied by an alternative transfer. Ducks Unlimited will facilitate the wetland projects. They have a ten-year history along the South Platte River in Colorado of working cooperatively with agricultural producers, municipalities and industry to provide water through alternative agricultural water transfers and that provide water for multiple benefits. Ducks Unlimited has constructed several recharge wetlands or ponds conducive to providing high quality habitat for migrating waterfowl along the South Platte River. These projects contribute several other benefits including recreational hunting, bird watching and water quality improvements through contamination filtering. In addition, these projects have for many years provided recharge to the South Platte alluvial aquifer, which can be used as augmentation credits for agricultural producers irrigating with groundwater or to wildlife agencies through various agreements and contracts.

The project will be completed in several steps. The steps include the following

1. Investigate alternative transfer methods by researching engineering, legal, and administrative considerations for each method. Apply this knowledge to a list of candidate projects that are being considered by Ducks Unlimited.
2. Develop a draft Business Plan.
3. Select three projects from the list of candidate wetlands projects that can potentially be developed as a result of the grant.
4. To the extent allowed by the grant funding, use the Business Plan to facilitate an alternative water transfer for the three selected wetlands projects. As stated previously, grant funds cannot be used for design and construction of a project or to further a Colorado Water Court case.
5. Using the knowledge gained during the development of the wetlands projects, finalize the Business Plan and prepare it for distribution to the general public.
6. Conduct workshops to provide training in the use of the Business Plan.
7. Write a summary report to the CWCB. The summary report will be available to the general public and will highlight knowledge gained during this project that can be applied statewide.

One of the program goals is to provide a perpetual water supply for users other than agriculture. The CCGA Team feels that this project can result in perpetual supplies for several reasons:

- The CCGA has suggested the development of a "perma-lease" instrument, which would provide lease terms that include provisions for readjusting levels of compensation to reflect market conditions, while allowing for permanence in water asset ownership by agricultural interests. If successful, this type of instrument could make long-term leases more attractive both to municipal interests who desire long-term use arrangements and to agricultural producers who desire to preserve irrigated agriculture for future generations.
- A recent survey conducted by Colorado State University suggested that at least 60% of respondents were willing to lease water rather than sell so long as they are suitably compensated. It suggests there is enough interest among agricultural water owners to justify this effort. This project will provide tools in the Business Plan that agricultural producers can use to establish levels of compensation that would allow them to lease water without transferring ownership.
- Ducks Unlimited projects ensure long term transfers by using conservation agreements which include leases of water for 30 years and conservation easements which provide protection of water supplies in perpetuity. The use of these legal tools ensures that water supplies and lands remain in agriculture and/or open space. This effort, through the development of the three wetlands projects, will demonstrate to producers that long-term leases are possible and can be profitable to their farming operations.

In addition to the above, the CCGA team is anticipating that by developing the Business Plan tools and by providing some publicity and education on the tools, agricultural producers will feel that they have more control over their water rights assets and will be more likely to enter into long term leases.

It should be noted that the CCGA does not anticipate that this project will end permanent transfers of agricultural water to other uses. It is important to remember that agricultural producers are the owners of water rights and can sell their rights if they choose. The CCGA feels that there is currently a trend for non-agricultural water interests to buy water rights as a hedge against future inflation of water prices. However, it is also felt that non-agricultural water users are primarily interested in reliability of supply rather than ownership in and of itself. As these interests satisfy their needs for purchased water, it is anticipated that there will be increased demand for temporary transfers of water to fulfill dry-year and other water needs. The results of this project will be applicable both as a potential alternative to purchased water and to directly fill the need for temporary transfers. In addition, this program will provide alternatives to producers that they may not have fully understood in the past, and the CCGA is confident that this project will result in future perpetual leases of water that allow for the preservation of irrigated agriculture.

REFERENCES/CONTACTS

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CHANGING CUSTOMERS — A CASE STUDY OF URBANIZATION EFFECTS ON OPERATIONS IN FRESNO IRRIGATION DISTRICT

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ABSTRACT

Fresno Irrigation District (FID or District) has historically provided irrigation water to approximately 245,000 acres in California's Central San Joaquin Valley. As the City of Fresno and its suburb to the east the City of Clovis have grown, farmland has been converted to homes and businesses. Fresno, Clovis and FID have agreements in which the cities receive the annexed land's water allocation. After years of urbanization and expansion of the cities' respective boundaries, the cities had acquired a significant entitlement to water delivered by FID. Until 2003 Fresno and Clovis relied solely on groundwater to meet the needs of their combined 500,000 residents. They each used their allotment to recharge the local groundwater aquifer. To continue to meet the needs of their growing cities, Fresno and Clovis each built surface water treatment plants served from FID's Enterprise Canal. Providing service to the surface water treatment plants has changed the way FID must operate the Enterprise Canal. Issues such as an extended delivery season, additional maintenance, increased flowrates due to concentrated demands, and facilities improvements needed to be addressed prior to bringing the surface water treatment facilities on-line. To address these issues, studies were undertaken, and a construction program of irrigation system improvements was developed and has commenced. This paper will discuss how FID has adjusted to these operational changes and how these changes have affected their system.

INTRODUCTION AND BACKGROUND

FID's surface water supplies come primarily from the Kings River, with some supplemental supplies coming from the San Joaquin River through the Friant-Kern Canal. The Cities of Fresno and Clovis (Cities) both have a majority of their incorporated area within the FID boundary. As the Cities have grown, they have utilized only groundwater for the water supplies. While the Cities were growing, they were able to secure the irrigation supplies for the developed lands. In addition, the City of Fresno secured a contract from the U.S. Bureau of Reclamation for a Class 1 supply from the Friant Unit of the Central Valley Project. Figure 1 is a regional map of FID and the Cities.

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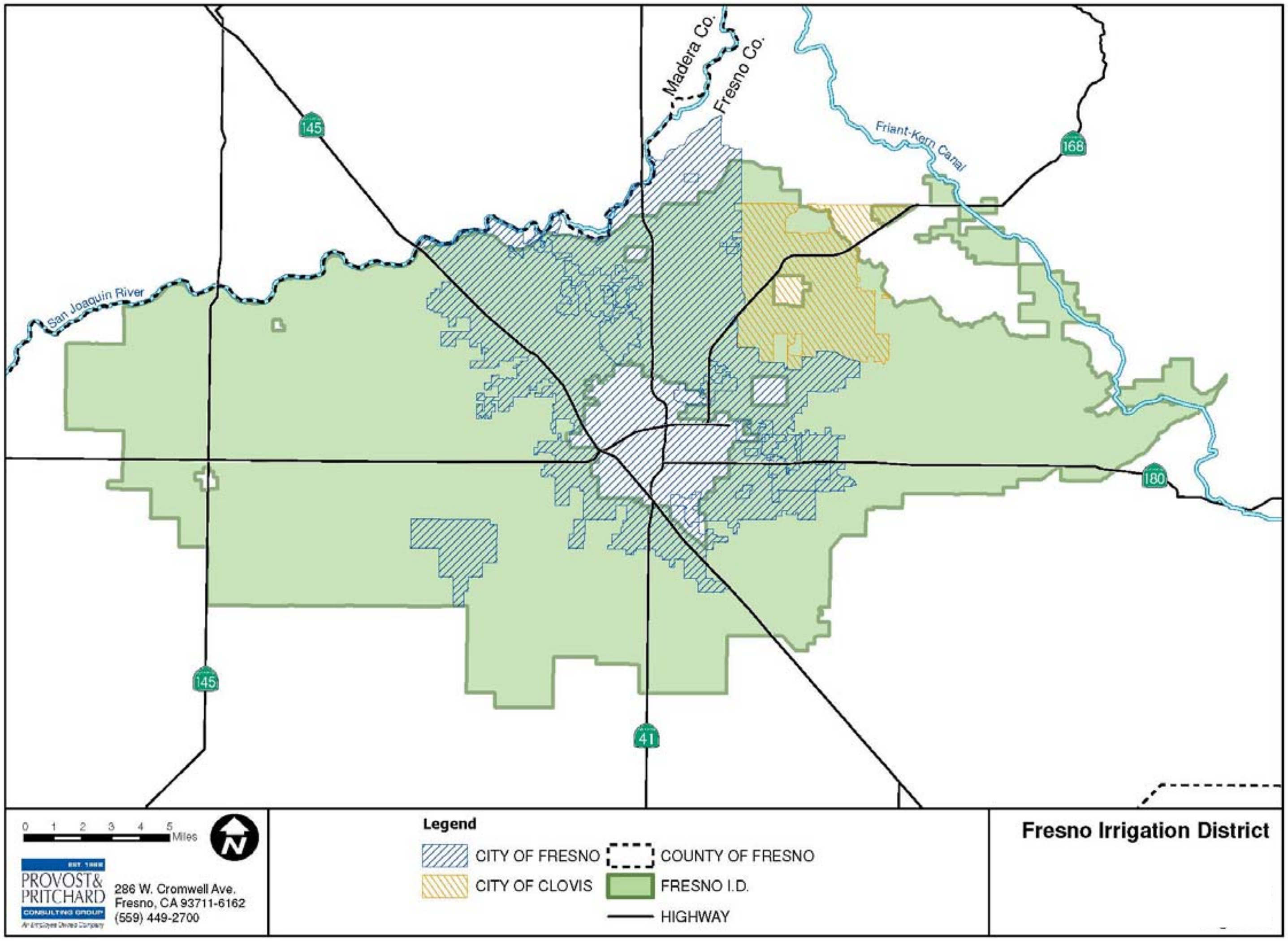

Figure 1. Map of the Fresno Irrigation District

In Fresno County the groundwater aquifer is in a state of overdraft - the extent of which is debatable - but nonetheless the current rate of groundwater pumping cannot be sustained. Realizing this, the Cities of Fresno and Clovis began in the 1990's to investigate the prospect of building surface water treatment facilities to better serve their customers, and also reduce their groundwater pumping. As the Cities have grown, they have negotiated with FID the ability to secure the irrigation entitlements of the developed land. This has given both Cities access to fairly stable surface water supply.

INVESTIGATION

In 2001 a joint study was initiated between the Cities of Fresno and Clovis, and FID. The study investigated how to utilize the District's 28 mile long Enterprise Canal along with a 7 mile reach of the Gould Canal to deliver surface water to each Cities' surface water treatment facility (SWTF). The land the Cities' annexed over the years had been served by a number of FID's canal systems. To use the Enterprise Canal, the Cities' would need to consolidate their demand into one canal system. Also, since the Enterprise Canal would be serving a SWTF, the State of California Department of Public Health (CDPH) required a Potential Contaminant Assessment (PCA) be performed, and an action plan for mitigating the potential for contamination.

Demand Analysis

To begin the investigation a demand analysis was performed. Since the Cities both planned to phase the construction and operation of their facilities over a number of years, the Cities and FID agreed to analyze three scenarios. The existing condition set a baseline of current FID irrigation delivery obligations. The initial condition would determine the near-term improvements which would be made to the Enterprise Canal. The ultimate condition would determine the how much water would need to be delivered for both urban and agricultural uses. More specifically the scenarios were defined as:

> Existing Condition: Existing peak irrigation demands and flows being conveyed by the cities to recharge basins.
>
> Start-Up Condition: Existing peak irrigation demands and half of the demands from the SWTFs (45 cfs – Fresno, 34 cfs – Clovis). If necessary, flows for recharge basins would be eliminated from the peak flow calculation.
>
> Ultimate Condition: Reduced peak irrigation demands due to the planned conversion of agricultural land to urban, and the full demands of the SWTFs (90 cfs – Fresno, 68 cfs – Clovis). The conversion of agricultural land to urban was based on each cities' general plan for year 2025.

Irrigation demand was calculated in each case using the irrigated acreage in each of the Enterprise Canal's lateral service areas. FID uses a rotation schedule for deliveries with 0.1 cfs per acre for a 24 hour period, twice per month. This flowrate by acreage calculation was performed and compared against historical records. A slight difference between the required flowrates and historical maximums was found. This difference was expected, as FID cannot provide water to the same amount of acreage each day and growers tend to take more water than ordered.

In order to account for this variation, a peaking factor for the system was calculated. By dividing the maximum record flowrate by the required daily flowrate a peaking of 1.15 was established. The peaking factor was then applied to all of the flowrates in the system to determine a maximum required flowrate. Losses along the canal, such as seepage and evaporation, were also accounted for in the peaking factor. Table 1 lists the results of the demands at significant key locations along the Enterprise Canal.

Table 1. Summary of Required Flowrates at Key Locations.

	Existing	Initial	Ultimate
Fresno SWTP	41	86	117
Big Dry Creek	124	164	170
Clovis SWTP	140	218	261
Enterprise Headgates	230	303	332

Capacity Analysis

To perform the capacity analysis, data about the existing canal was gathered. A topographic survey of the entire Enterprise Canal using GPS equipment was conducted to gather cross-sections and data at the various bridges, culverts and check structures. Cross-sections were gathered at approximately 500 foot intervals along the entire 28 mile canal alignment. The survey data was analyzed using AutoCAD software, and then exported into HEC-RAS to evaluate the hydraulics of the Enterprise Canal. To gather information about the maximum flows, a flow test was conducted during the peak of the irrigation season. Flows were measured at each check structure and the high water levels at various bridges and structures recorded.

A calibration run of the HEC-RAS model was used to check the accuracy of the model. Water levels upstream of each check structure were constrained to the observed levels to properly model the FID's operations of the check structures. The flow data was input to the HEC-RAS model and the water levels calculated by the model were compared to the observed water levels. Adjustments to the model were then made where necessary to better match the observed and calculated water levels.

Once calibrated, the calculated demands for each of the three scenarios (existing, initial, and ultimate) were used as the basis for flows and modeled with the existing geometry of the canal. For all of the models, a minimum freeboard of 1 foot was used to determine where improvements might be needed. The HEC-RAS model runs revealed a number of constrictions in the canal which severely limited how much the capacity could be safely increased.

Based on the identified constrictions, five separate geometric models were developed for the canal modifications. These included a 10 cfs, 25 cfs, 50 cfs, 73 cfs (full initial condition flows), and 102 cfs (full ultimate condition flows). The models allowed various channel improvements such as lining, deepening, widening, or raising the banks to be analyzed in an efficient manner. Figure 2 shows how the profiles of the canals were compared in order to determine the type of improvement needed.

For each of the models, a list of improvements was developed. Reconnaissance level cost estimates were then prepared to determine which improvements were cost-effective and develop a magnitude of the costs, which would be shared between the agencies. Table 2 below summarizes the costs for the incremental improvements up to the initial condition.

Table 2. Summary of Capacity Improvement Costs for Initial Condition.

Capacity Increase (cfs)	**Available Recharge[1] (AF/yr)**	**Recharge Increase from No Improvement[2] (AF/yr)**	**Total Capital Cost[3]**	**Cost[4] ($/cfs)**	**Cost[5] ($/AF)**	**20 year Annualized Cost[6] ($/AF)**
Existing	17,220	--	--	--	--	--
No Improvement	0	--	--	--	--	--
10	2,460	2,460	$362,656	$36,266	$147	$15
25	3,690	6,150	$2,389,560	$95,582	$389	$40
50	6,150	12,300	$4,010,053	$80,201	$326	$33
73	5,658	17,958	$6,047,284	$82,840	$337	$34

Notes:

1) Available Recharge calculated by converting the incremental increase in flowrate to acre-feet for the period between May 1st through August 31st. See Table 4.

2) The change in recharge is the total additional amount of water the capacity increase will provide above the No Improvement Option

3) The Total Capital Cost is the total cost required for improvements to increase the canal capacity by the amount shown.

4) The Cost Per cfs is the Total Capital Cost divided by the Capacity Increase.

5) The Cost per Acre-Foot assumes the capital for the project is recovered in the first year.

6) Assumes an 8% capital recovery rate.

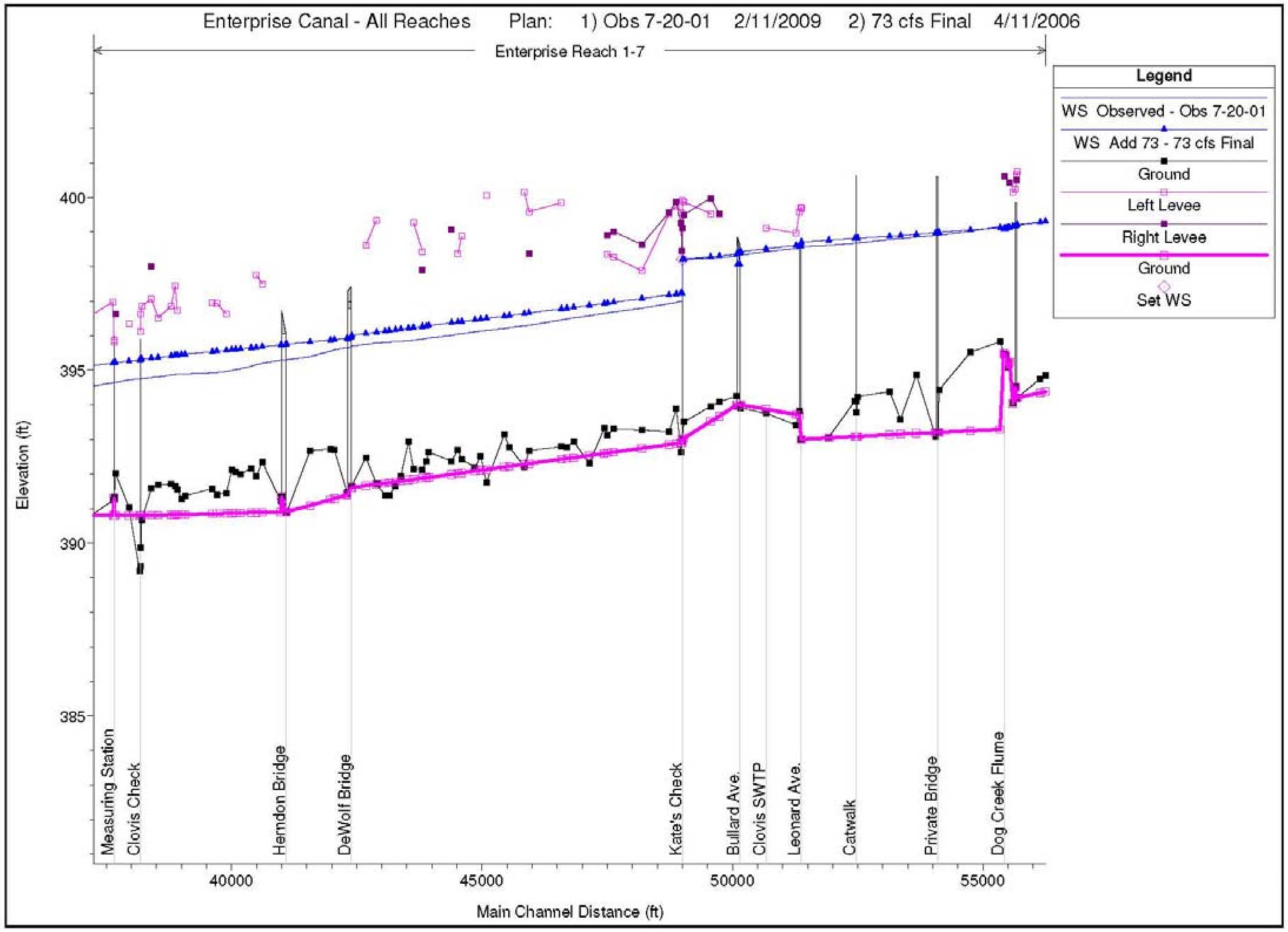

Figure 2. Hydraulic Profile of Enterprise Canal

Potential Contaminant Assessment

Following a Watershed Sanitary Survey completed in 1998, the Cities requested a report be prepared that provided a more detailed assessment of the possible contaminants, identify any changed conditions, and include typical solutions for the contaminants discovered. The objectives of this report were:

- Identify, quantify, and assess possible contamination sources along the Enterprise Canal and portion of the Gould Canal.
- Identify changes in the assessment since the Watershed Sanitary Survey performed in March 1998.
- Propose typical improvement measures for the identified possible contaminant sources.
- Provide a cost estimate for the typical improvement measures.

Most of the inventory was performed by using GPS survey equipment to locate the possible contaminants along the canals. The GPS receiver was equipped with an antenna receiving a US Coast Guard beacon signal. Prior to performing fieldwork, categories of contaminant source types were determined. Sixteen categories were organized to satisfy the project needs as shown in Table 3.

Table 3. Categories of Potential Contaminants.

Animal Evidence	Pipes
Building Locations	Pipe Crossings
Canal Erosion	Point Runoff
Debris Piles	Sheet Runoff
Fencing	Storage Tanks
Gate Locations	Trees
Land Uses	Vegetation
Lining	Miscellaneous

These categories were based on the recommendations of the Watershed Sanitary Survey report, and concerns CDPH expressed about the operation of the canal as a potable water source. Within each category, physical characteristics, or attributes, of the item were created to better describe the item. These attributes, including a digital photo, were collected for each item in the field. Figure 3 is an example of the maps and inventories developed for the assessment.

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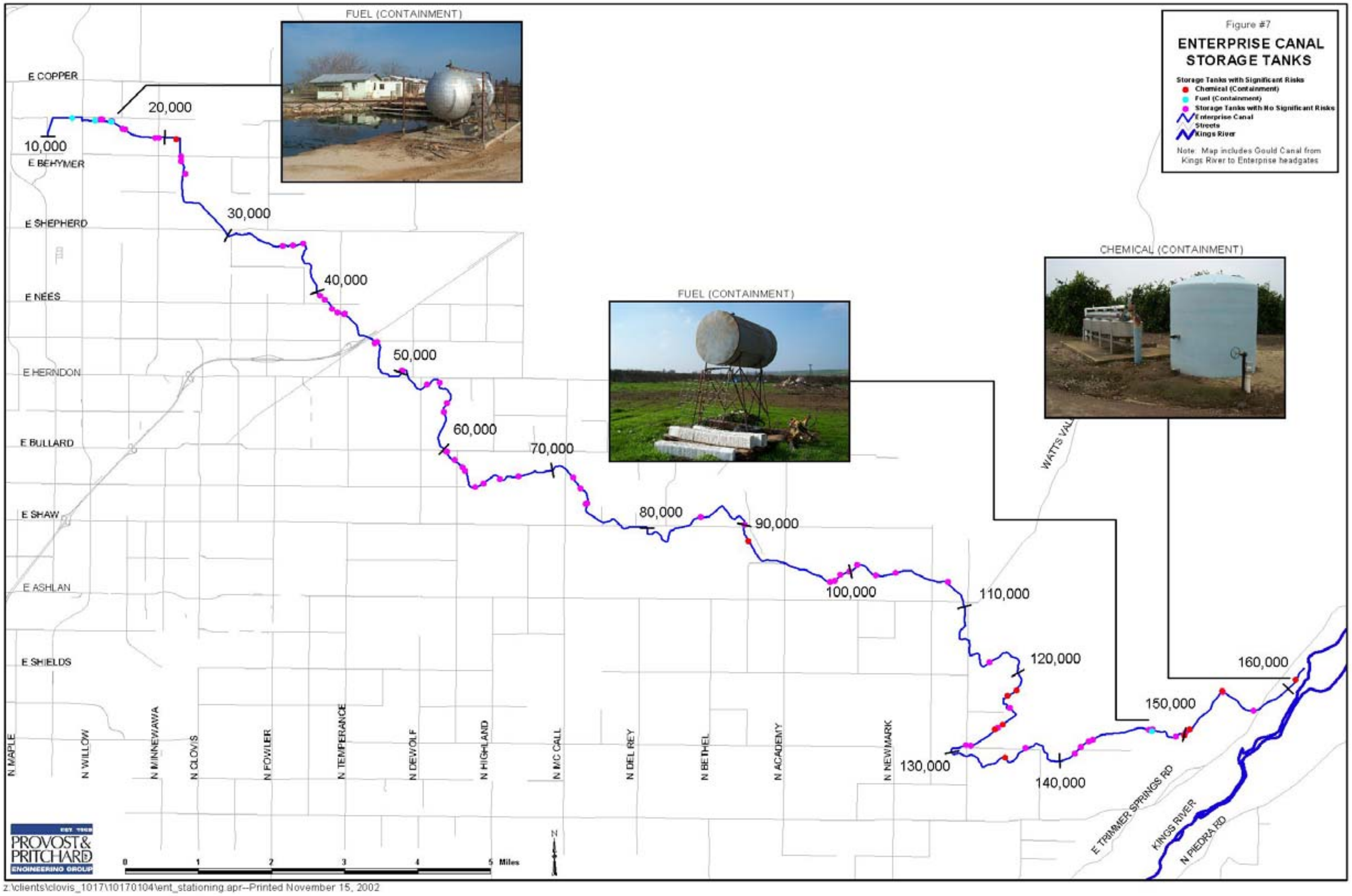

Figure 3. Map of Canal Showing Contaminants.

Typical solutions to remediate possible contaminant sources were then devised. The solutions were a broad-brush approach and only intended as a guideline for the needed improvements. The goal of establishing remediation methods was to develop an order of magnitude cost estimate. When the improvements were made, each solution was specific to each site. Solutions were developed for the following types of problems, originally identified in the 1998 Watershed Sanitary Survey: Runoff from streets, Discharge pipe removal/rerouting, Public access from streets, Animal access, Fuel containment, Chemical containment, and Debris removal.

RESULTS

Construction

Based on the results of both the capacity study and PCA, a construction plan was developed which identified improvements for both the capacity improvements and measures to address the potential contaminants. Table 4 below lists the improvements needed to be made to address potential contamination, and the sources' associated risk to the SWTFs.

Table 4. Summary of Contaminant Mitigation Measures and Costs

Item	Quantity	Unit	Typical Improvement Cost	Cost	Risk Level
Runoff and Discharge					
From Streets	26	ea	-----	-----	L
From discharge pipes					
Operational					
Runoff	34	ea	-----	-----	L
Tailwater	56	ea	$8,000	$448,000	H
Backflush	9	ea	$2,500	$22,500	H
Non-Operational	19	ea	$500	$9,500	VH
Fencing					
Public Access from streets	26	ea	-----	-----	L
Install wire fencing in pastured areas	60,083	lf	$3	$180,249	H
Provide Animal Crossings of Canals	2	ea	$15,000	$30,000	H
Chemical and Fuel Containment					
Construct fuel containment	4	ea	$21,000	$84,000	H
Construct chemical containment	11	ea	$22,500	$247,500	H
Miscellaneous					
Debris Removal	39	ea	$1,000	$39,000	L

Since 2002, improvements have continually been made to the Enterprise Canal. FID as the owner of the canal has taken the lead towards seeing that the capital improvements to canal are made. To date FID has spent millions to improve the canal, most of which has been reimbursed by the Cities. This has included excavating and dredging he canal to make the 10 cfs flow improvements, upgrading and automating the headworks of the canal, replacing a flume, removing drainage pipes, relocating fuel and chemical tanks, clearing the entire right of way on each side of the canal, and fencing areas to keep livestock from entering the canal. Within the next two years, FID plans to replace the another flume and building an all-weather road so at least one side of the canal can be accessed at all times.

Operations

The Cities agreed to implement certain operational requirements in lieu of building capital improvements to the Enterprise Canal. The Cities as the recipients of the surface water have taken the lead related to implementing these operations along the Enterprise Canal to operate their SWTFs. This takes into account remote water quality monitoring at select points on the canal and daily patrols of the canal. This is done to provide an early warning system to the Cities and shut the SWTFs down if contaminants are detected.

FID still performs the routine maintenance of the canal – typically weed control and dredging. The Cities and FID developed an agreement to operate the Enterprise Canal for 11 months per year, with all maintenance being done in November. This operational duration has caused FID to perform their maintenance on the Enterprise System on a very compressed schedule compared to their normal maintenance schedule of 4 to 6 months. The schedule tends to cause problems on construction projects, and requires careful, detailed planning for any construction or maintenance activities in which the canal must be dewatered.

The Enterprise Canal is typically an earthen channel. Prior to 2000, FID tended to utilize Magnacide® to control the aquatic weed growth. Since the SWTFs have become operational, FID must coordinate the application of weed control chemicals with the Cities. FID is also restricted to using copper sulfate to control aquatic weed growth. FID has seen only marginal success in using copper sulfate and typically resorts to mechanical methods to remove weeds when necessary.

SUMMARY

For the past five years the Cities have been treating surface water and it has helped to leave approximately 20 TAF of water in the aquifer over the last 4 years, benefitting not only the Cities, but growers on in the adjacent rural areas and helping to alleviate the local groundwater overdraft. The studies provided a guide for the improvements that were needed to improve the Enterprise Canal to convey a safe raw water supply to its municipal partners. This project is an excellent example of municipal and agricultural agencies working together to better utilize regional water supplies.

THE SUSTAINABILITY OF IRRIGATED AGRICULTURE IN THE LOWER COLORADO RIVER REGION

James V. Davey, PE, D.WRE[1]

ABSTRACT

There are some 160,000 acres of irrigated agriculture in the region of the Lower Colorado River from below Imperial Dam to the Mexican border. Included in this region are seven irrigation districts, 6 in Arizona and 1 in California, and these districts presently operate on a run-of-the-river basis, diverting waters from the Colorado River and returning flows to the river through agricultural drains and groundwater flows.

Demand for water is increasing in the region due to urbanization, particularly the rapidly growing City of Yuma but also the cities of San Luis, Somerton and Wellton, Arizona. Mexico also diverts large volumes of surface water and increasingly relies on groundwater pumping to meet it water needs. The region presently has areas of groundwater excess, where drainage wells and open drains are needed to relieve high groundwater tables, and areas of declining groundwater tables, especially near the border areas with Mexico and potentially along the lower Gila River. Treaty requirements negotiated with Mexico regulate salinity of return flows to the river, resulting in much water being bypassed to the Santa Clara slough in Mexico and potentially being desalted on a large scale basis by the Yuma Desalting Plant in the future.

Sustainability of irrigated agriculture over the long term for this region will depend on many factors, including (1) the overuse of groundwater supplies, especially along the lower Gila River and along the Mexican border area; (2) the reduction in surface water supplies due to water conservation; (3) reduction in groundwater recharge as flood events on the Colorado and Gila Rivers become even more infrequent with continued construction of upstream flood control storage; and (4) general impacts on agriculture and water rights from conversion of agricultural lands to urban uses.

INTRODUCTION

Geographic Area

The Lower Colorado River area as used in this paper is the area in both Arizona and California from Imperial Dam, about 20 miles north of the city of Yuma, Arizona, to the southerly Mexican border about 20 miles south of Yuma (Figure 1.) Included in this Lower Colorado River area are the run-of-river irrigation districts that divert water from the Colorado River along with municipal users of Colorado River water and users of groundwater in the recharge area of the Colorado River.

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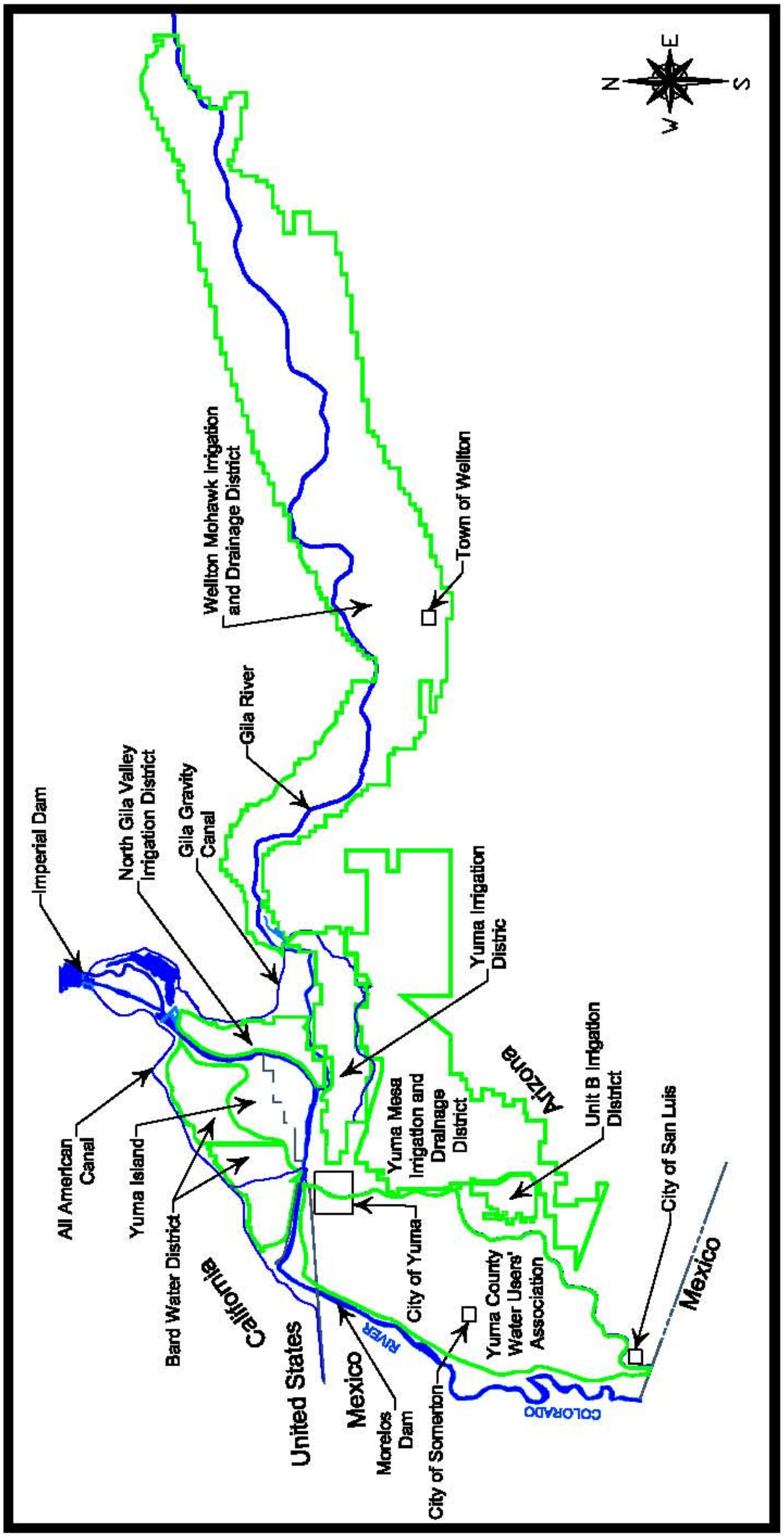

Figure 1. Location Map

Not fully included in the study area but of importance on the area wide hydrologic balance are the out-of-basin diversions of Colorado River water to Mexico and the Imperial Valley, eventually draining to the Salton Sink, and the run-of-river diversions to Mexico that are diverted in the study area but are linked hydrologically more to lands further south in the delta region of the Colorado River.

The geographic area also includes the lower 50 miles of the Gila River, a major river draining much of central and southern Arizona, parts of western New Mexico and a area of northern Mexico. This stretch of the Gila River is irrigated with surface water diverted from the Colorado River.

Major Water Users of the Study Area

The seven principal irrigation districts in the study area are Bard Water District (BWD) in California and in Arizona the North Gila Valley Irrigation Drainage District (NGVID), Wellton-Mohawk Irrigation and Drainage District (WMIDD), Unit B Irrigation District (Unit B), Yuma Irrigation District (YID), Yuma Mesa Irrigation and Drainage District (YMIDD) and the Yuma County Water Users' Association (YCWUA). Between these seven districts some 160,000 acres of agricultural lands are irrigated by surface water diversions. Note that not all these are irrigation districts in the legal sense (for example, BWD is a State of California Water District and the YCWUA are organized as a Water Users' Association) but for the sake of simplicity they are all referred to as irrigation districts in this paper.

The major municipal water users in the study area are the City of Yuma, the City of San Luis, the City of Somerton, and the Town of Wellton, all in Arizona. Other municipal water users include the unincorporated town of Winterhaven in California, the Quechan Indian Reservation, mostly in California, the Cocopah Indian Reservation in Arizona (including the North, West and East Reservations) and various unincorporated area with residential, commercial or industrial developments. Water use by these users includes both the diversion of surface water from the Colorado River and the use of groundwater.

Diversions to California's Imperial Valley are made by the All-American Canal from Imperial Dam. While these are primarily out of basin flow, with any resulting return flows ending up in the Salton Sea, the canal itself loses flows to seepage as it passes by the Bard Valley and these seepage losses eventually contribute as return flows to the Colorado River.

Water use by Mexico consists of both surface water diversions at Morelos Dam, a diversion dam roughly due west of the City of Yuma, of groundwater pumping west of the Colorado River between the northerly and southerly Mexican borders (referred to as the Northerly International Border, NIB, and the Southerly International Border, SIB, with the Colorado River between the two referred to as the Limitrophe Section) for agricultural uses, and water pumping south of the SIB for agricultural and municipal uses. The surface water diversion are primarily used for agriculture in the Mexicali Valley, and as there exists a drainage divide within the Mexicali Valley, return flows either go northerly via the New and Alamo Rivers to the Salton Sea (out of basin) or go southerly to return to the Colorado River as it nears the Gulf of California.

It should be noted that all United States diverters of surface flows of Colorado River water have water right entitlements with the US Bureau of Reclamation and the states of Arizona or California. Groundwater users may or may not have entitlements to Colorado River water.

Water Supply Sources

The major water surface water supply sources in the study area are the mainstream Colorado River and the flows of the Gila River. The Colorado River is regulated by the upstream dams (primarily Hoover and Glen Canyon Dams) and flows are normally released to the Yuma area based on water orders submitted to the US Bureau of Reclamation. Flood flows occur infrequently due to the release of upstream flow from the dams as they near capacities and also minor flood flows occur when local runoff enters the Colorado below Hoover Dam.

Water supply from the Gila River above the study area is the result of infrequent but often significant flood releases from upstream reservoirs in Central Arizona. These releases occur rarely, perhaps occurring only once a decade, but when they do occur, they often have a duration of many months and can result in significant recharge of the aquifers along the lower Gila River. The Gila River is not used as a surface water supply source.

Ground water supplies are available in the alluvial aquifers bordering the Colorado and Gila Rivers throughout the study area. These supplies are a combination of a base storage component that pre-dates the modern use of Colorado River water for irrigated agriculture and of a recharge component from surface water irrigation. Many studies of the hydrogeology of the Lower Colorado River area have been conducted, most recently by US Geological Survey as Scientific Investigations Report 2006–5135 (Dickinson, et al., 2006)

Return Flows

The return flows to the Colorado River in this area are an important part of the overall hydrologic accounting, being accredited to the entitlements of the various water right holders.

Return flows in the study area occur either through drainage canals and pipelines flowing directly to the Colorado River, drainage canals flowing to Mexico, or groundwater recharge that in turn eventually returns to the Colorado River or is used by other water users. There are many groundwater drainage wells that pump return flows to the drain systems. It should be noted that return flows in the study area, particularly groundwater return flows, are of higher total dissolved solids content than Colorado River water and thus return flows may not be productively used (such as flows to the Santa Clara Slough as discussed below) or are delivered to Mexico in accordance with the requirements of the Mexican Treaty and thus are limited in quantity by the treaty.

CURRENT AGRICULTURAL WATER USE

The net agricultural water use by each of the seven irrigation districts in the study along with agricultural users outside of the irrigation districts varies considerably depending on many factors. The net use and the factors affecting this use are presented below for each of these districts and other major users.

In reviewing the agricultural water users, the first described are the two pure run-of-river districts, Bard Water District and North Gila Valley Irrigation District. These districts have relatively simple water supply and return flow regimes, both being fed from and draining directly to the Colorado River. Next the described are the interconnected districts of Yuma Irrigation District, Yuma Mesa Irrigation and Drainage District, Unit B Irrigation District and the Yuma County Water Users' Association. Two of these districts, Yuma Mesa and Unit B, are on mesa lands above the other two districts and contribute return flows to the two valley districts, Yuma Irrigation District and the Yuma County Water Users' Association. The Yuma County Water Users' water usage is also affected by their neighbor to the west and south, Mexico. Lastly, the Wellton-Mohawk Irrigation and Drainage District is perhaps the most self-contained of the districts, having both valley and mesa lands, handling its own drainage and return flows, and further having the potential for groundwater recharge from the Gila River should groundwater levels decline from excess use.

Water use and physical data about the irrigation districts cited below are primarily from the U.S. Bureau of Reclamation's project Yuma Project and Gila Project web sites (www.usbr.gov) and from the Arizona Department of Water Resources web site (www.azwater.gov). Water rights data is primarily from the summaries contained in "Updating the Hoover Dam Documents" (Nathanson, 1978).

Bard Water District (BWD)

The Bard Valley is the floodplain land on the California side of the Colorado River from just a few miles below Imperial Dam and then north and west of the City of Yuma. Bard Water District is the operating agency for Reservation Division of the U.S. Bureau of Reclamation's Yuma Project. The Reservation Division consists of two units, the Bard Unit, an area of privately owned lands, and the Indian Unit, lands that are a part of the Quechan Indian Reservation. There are about 14,700 acres of irrigated land in Bard Water District.

BWD has Colorado River water rights with a priority date of 1905 for lands in the Bard Unit and 1884 for the Indian Unit. These water rights are beneficial use rights and thus not strictly quantified though the Bard Unit has listed for it a present perfected right of 21,162 acre-feet and the Indian Unit has water rights that were set at a diversion of 51,616 acre-feet but that are also still litigated.

Water use in district for the 2008 calendar year consisted of total diversions from the Colorado River of 89,914 acre-feet, total measured and unmeasured return flows of 44,680 acre-feet and total consumptive use of 45,234 acre-feet. Measured return flows are collected in open drains and are affected by All-American Canal seepage, seepage from agricultural lands, and in years of high Colorado River flows, the generally high water table caused by the river. Unmeasured return flows are generally bank flows seeping into the adjacent Colorado River.

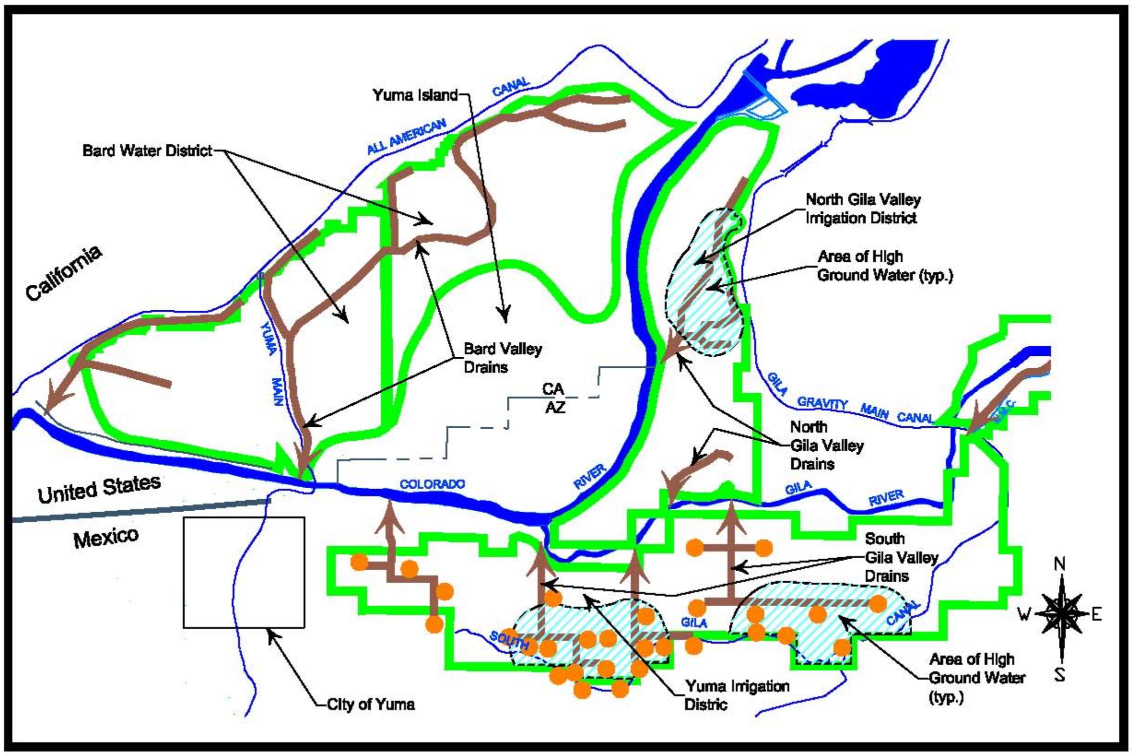

Figure 2. Bard Water District, North Gila Valley Irrigation District and Yuma Irrigation District

Within BWD is very little groundwater use and very little urban development. The small town of Winterhaven, California is included in the boundaries of the District but it has shown little growth, which is mostly attributable to being landlocked by the Quechan Indian Reservation. The development of the Quechan Reservation inside the BWD boundaries has been limited, also.

To the east of BWD but adjacent to it is what is known as the Yuma Island, an old cut off meander of the Colorado River that is substantially farmed. The Yuma Island, though now on the California side of the River, is about half in Arizona and half in California – a compromise by the two states. Most of the agriculture on the Island gets its water supply by pumping groundwater or pumping directly from the Colorado River, with one area (Ranch 5) receiving Colorado River water from the BWD delivery system. Water rights are complicated for the Island water users, with Ranch 5 water use being accounted for directly to the Quechans and other water users having limited quantified rights.

North Gila Valley Irrigation District (NGVID)

The North Gila Valley is the land opposite the Bard Valley, lying east of the Colorado River and north of the Gila River. Originally constructed as a part of the Yuma Project, the district became the North Gila Unit of the Mesa Division of the Gila Project following the completion of the Gila Gravity canal in the 1940's. The District includes some 6500 irrigated acres.

NGVID has Colorado River water rights with a priority date of 1909. These water rights were originally beneficial use rights but have been quantified through Gila Project contracts such that NGVID has present rights to 29,650 acre-feet per year of consumptive use, including 2500 acre-feet that can be used for municipal uses.

Water use in NGVID for the 2008 calendar year consisted of total diversions from the Colorado River of 47,944 acre-feet, total measured and unmeasured return flows of 33,983 acre-feet and total consumptive use of 13,961 acre-feet. Measured return flows are collected in open drains and are affected by Gila Gravity Canal seepage, seepage from agricultural lands, and in years of high Colorado River flows, the generally high water table caused by the river. Unmeasured return flows are generally bank flows seeping into the adjacent Colorado River.

There is very little existing or planned urban development in the North Gila Valley and very minor groundwater use.

Adjacent to and east of the NGVID is the Gila Monster Ranch, an area of about 2800 acres with some 9000 acre-feet of Colorado River water rights of various priorities. The Gila Monster Ranch both diverts from the Gila Gravity Canal and uses groundwater, with substantial return flows similar to NGVID.

Yuma Irrigation District (YID)

The South Gila Valley is the valley land between the Yuma Mesa to the south and the Gila and Colorado Rivers to the north. Originally irrigated by an extensive system of wells, YID was formed in 1962, entering into a contract with the US Bureau of Reclamation as the South Gila Valley Unit of the Mesa Division of the Gila Project. There are about 10,600 acres of irrigated land in Yuma Irrigation District.

YID has Colorado River water rights as a part of the Gila Project contracts such that YID has present rights to 47,700 acre-feet per year of consumptive use plus 5,000 acre-feet that can be used for municipal uses.

Water use in the district for the 2008 calendar year consisted of total diversions from the Colorado River of 69,686 acre-feet, total measured and unmeasured return flows of

30,149 acre-feet and total consumptive use of 39,537 acre-feet. Measured return flows are collected by deep drainage wells and pipeline or open channel drains and are affected by the Gila Gravity Canal seepage, seepage from agricultural lands, and in years of high Colorado River flows, the generally high water table caused by the river. In addition, as YID is located at a lower elevation than the Yuma Mesa to the south of it, the deep percolation from irrigation on the Yuma Mesa flows into the South Gila Valley. These groundwater flows from the Yuma Mesa are substantial and are the cause of needing to use deep drainage wells to lower the groundwater table.

YID continues to use groundwater wells to supplement its surface water diversions. In addition, some adjacent lands are irrigated using wells.

There is a moderate level of urban activity in the YID boundaries. The City of Yuma is encroaching into the western end of the district and scattered urban developments are found in various areas of the District.

Yuma Mesa Irrigation and Drainage District (YMIDD)

The Yuma Mesa is the higher land between the Gila and Yuma Valleys, stretching from the City of Yuma south to Mexico. The lands on the Yuma Mesa are about 50 to 100 feet above the valley lands, thus requiring a pumping plant to deliver irrigation flows. Its sandy soils are well suited to citrus and hay cultivation. The two irrigation districts on the Yuma Mesa are Yuma Mesa Irrigation and Drainage District and the Unit B Irrigation District, which is adjacent to and west of YMIDD. YMIDD is the Mesa Unit of the Yuma Mesa Division of the Gila Project. It can irrigate 20,000 acres of land within its boundaries.

YMIDD, authorized as a part of the Gila project in 1937, has Colorado River water rights to 104,000 acre-feet per year of consumptive use plus 10,000 acre-feet that can be used for municipal uses. As with the other Yuma Mesa Division projects, it also has the potential for supplemental water use.

Water use in the district for the 2008 calendar year consisted of total diversions from the Colorado River of 191,796 acre-feet, total measured and unmeasured return flows of 107,056 acre-feet and total consumptive use of 84,740 acre-feet. Measured return flows are collected by the USBR drainage facilities (drainage wells and pipelines) along the western edge of the Yuma Mesa and in the Gila and Yuma Valleys. With the generally sandy soils of the Yuma Mesa lands, the deep percolation component of water use is significant and over time there has developed a significant body of groundwater under the Yuma Mesa, the Yuma Mesa groundwater mound. Groundwater flows are not only to the Yuma and Gila Valleys but to the south towards Mexico, where they are intercepted by both the U.S. Bureau of Reclamation's 242 Wellfield system (named after Minute 242 of the Mexican Treaty) and by well fields in Mexico.

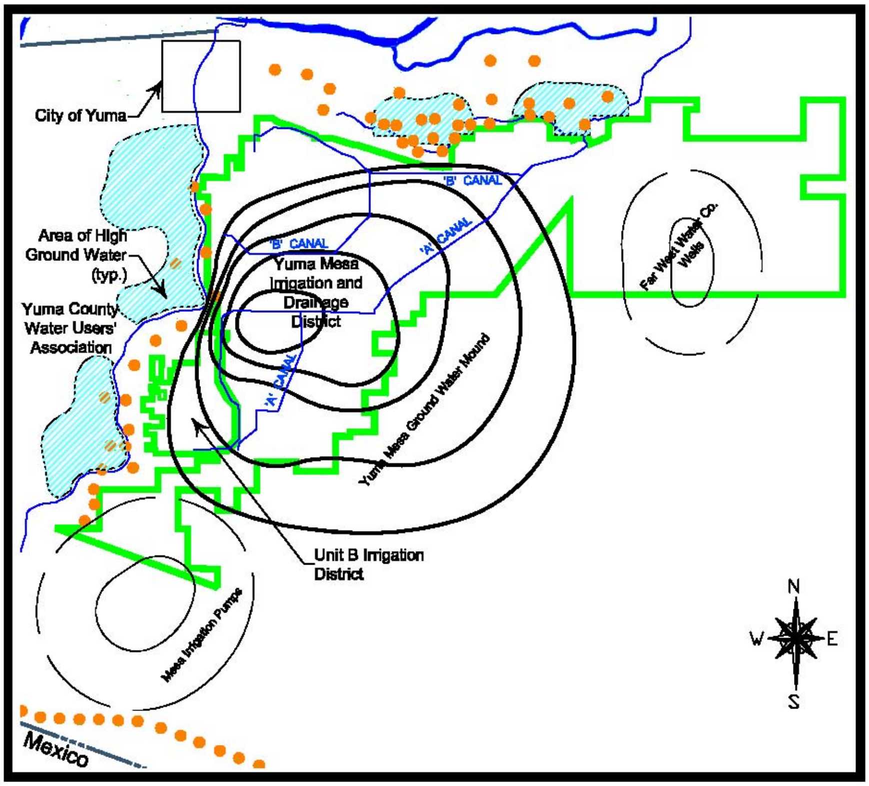

Figure 3. Yuma Mesa Irrigation and Drainage District and Unit B Irrigation District

Urban and suburban development occurs throughout YMIDD. In the northern part of the district the City of Yuma is growing at a fairly rapid rate. This includes industrial lands around the Marine Corps Yuma Air Station and Yuma International Airport. In scattered areas throughout the district are developments known locally as ranchettes, typically two acre residential parcels that may or may not use irrigation water. It should be noted that arable land is available to the south of the present agricultural lands of the District to allow expansion of the District to replace urbanized lands. There are a fair number of groundwater wells within the District boundaries and adjacent to it.

Unit B Irrigation District (Unit B)

Also on the Yuma Mesa and adjacent to the YMIDD, Unit B Irrigation District is the smallest of the Irrigation Districts in the study area with 3,305 acres that can be irrigated. Unit B was originally authorized in 1917 and constructed as a part of the Yuma Project. It has unquantified Colorado River water rights, with 6800 acre-feet of those rights considered present perfected rights.

Water use in the district for the 2008 calendar year consisted of total diversions from the Colorado River of 26,894 acre-feet, total measured return flows of 13,172 acre-feet (no unmeasured return flows were credited to it) and total consumptive use of 13,722 acre-feet. Measured return flows are primarily from the groundwater pumped to the U.S. Bureau of Reclamation's Yuma Mesa Conduit along the western edge of the Yuma Mesa. As with YMIDD, the generally sandy soils of the Yuma Mesa lands result in significant

deep percolation and contribute to the Yuma Mesa groundwater mound. Groundwater flows are primarily to the Yuma Valley and south to Mexico.
Much of Unit B has been developed into 2-acre ranchettes and as a result the overall agricultural production and water use in the District has declined.

Yuma County Water Users' Association (YCWUA)

The oldest irrigation district (actually a Water Users' Association rather than an Irrigation District) in the Arizona portion of the study area is the Yuma County Water Users' Association, formed in 1903 to contract with the U.S. Bureau of Reclamation for the construction of the Yuma Project. The YCWUA operate and maintain the Valley Division of the Yuma Project, which consists of about 53,415 irrigable acres, of which about 43,000 are currently in agriculture.

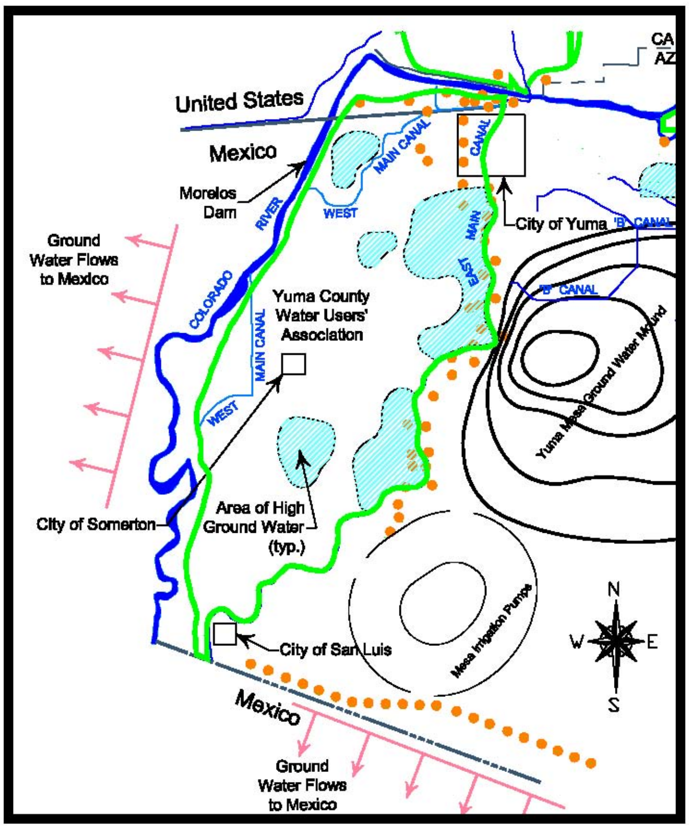

Figure 4. Yuma County Water Users' Association

The water rights of the YCWUA are individual beneficial use water rights of which 254,200 acre-feet are present perfected Colorado River water rights and additional unquantified priority 2 water rights. These water rights date from the 1890's.

Water use in the Association for the 2008 calendar year consisted of total diversions from the Colorado River of 348,121 acre-feet, total measured and unmeasured return flows of 95,418 acre-feet and total consumptive use of 252,703 acre-feet. Measured return flows are collected in open drains and by groundwater drainage wells. Groundwater sources to the Yuma Valley include seepage from the Colorado River from above Morelos Dam (and from below Morelos in years of high river flows) and groundwater flows from the Yuma Mesa groundwater mound, as wells as from percolation from water applied to the lands of the Yuma Valley. Unmeasured return flows include groundwater that percolates from the Yuma Valley to the normally mostly dry Colorado River below Morelos Dam and groundwater that is pumped from under the Yuma Valley by groundwater supply wells in Mexico (the wells in Mexico pump a combination of water lost from the Colorado River and water percolating from Yuma Valley lands.)

There is significant urban development within the lands of the YCWUA, including the City of Yuma to the north, the City of Somerton in the central part of the Yuma Valley and the City of San Luis at the southerly Mexican border. Each of these cities is growing but overall growth is slower in the valley lands than it is on the adjacent mesa lands. The East, West and North Cocopah Indian Reservations are within or adjacent to the YCWUA and the reservation lands are a mix of agricultural and urban developments and they also have their own water rights. There are also several small water right contractors adjacent to the YCWUA, including, for example the USBR Yuma Area Office, Yuma Union High School District, and several private water contractors.

The City of Yuma has an individual water right contract for Colorado River Water rights but also has a water conversion contract with the YCWUA such that they can deliver water from lands with water rights as municipal or industrial water rather than as agricultural water. The City's of San Luis and Somerton have or are developing similar conversion contracts.

Wellton-Mohawk Irrigation and Drainage District (WMIDD)

The Wellton-Mohawk Irrigation and Drainage District is the most geographically and operationally distinct of the Yuma area irrigation districts. It is the Wellton-Mohawk Division of the Gila Project and includes land along both sides of the Gila River from about the Gila Mountains east to the Mohawk Mountains. WMIDD can provide irrigation water to 65,000 acres, including both the valley lands along the Gila River and adjacent mesa lands to the south of the Gila. WMIDD, as a part of the Gila project, has Colorado River consumptive use water rights to 278,000 acre-feet per year.

Water use in WMIDD for the 2008 calendar year consisted of total diversions from the Colorado River of 402,373 acre-feet, total measured return flows of 107,056 acre-feet and total consumptive use of 145,204 acre-feet. Being the only irrigation district in its geographic area, WMIDD has no direct unmeasured return flows – all water lost to seepage contribute directly to the groundwater table or to the Gila River, and Gila River flows, both surface and subsurface, are measures as they leave the WMIDD project area.

Measured return flows are collected by drainage facilities (drainage wells and drainage channels) throughout the project area and the collected drainage flows, due to their relatively high salinity, are conveyed by the USBR's Main Outlet Drain and Main Outlet Drain extension along the Gila and Colorado Rivers, past YID and the YCWUA, and into

Mexico to the Santa Clara Slough. The lands in WMIDD were for many years irrigated by well water and thus accumulated excessive salts in the soils which were then leached out in the early years of receiving Colorado River water. While salt concentrations in drainage flows have declined from their early peaks, the drainage waters are still bypassed to the Santa Clara Slough as such allows the U.S. to comply with the salinity requirements agreed to with Mexico. The Yuma Desalting Plant, located in the northern Yuma Valley, is designed to desalt the WMIDD drainage flows during times when treaty obligations cannot be met through river flows, but since its construction it has not been needed.

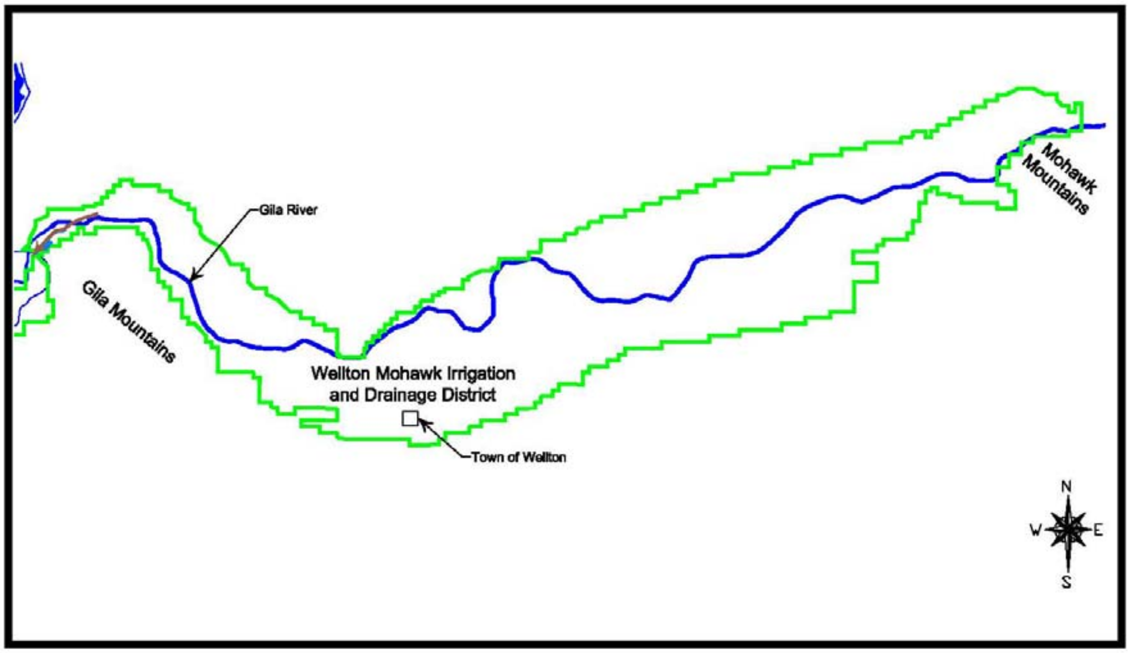

Figure 5. Wellton-Mohawk Irrigation and Drainage District

Groundwater recharge in WMIDD is typically from the percolation of irrigation water. The groundwater drainage wells in the area are operated to maintain the groundwater table at acceptable levels for farming in the valley areas. The Gila River is normally dry upstream of WMIDD but can contribute significant regional groundwater recharge during years when it flows, which due to the release criteria of Painted Rock Dam, the upstream flood control dam, are designed to minimize flood damage along the Gila River and result in Gila River flows through the project area last many months.

There is some urban development occurring in the mesa areas of WMIDD, notably around the Town of Wellton, but such development is still relatively minor in comparison to the acreage in the district. There are some groundwater wells pumped for municipal, industrial and agricultural uses, primarily on the mesa lands to the south of the Gila River.

SUSTAINABILITY OF AGRICULTURAL IN THE LOWER COLORADO RIVER AREA

The Lower Colorado River area has at present an agricultural economy that encompasses some 160,000 acres of farm land and agriculture produces some $1 billion in economic activity in the area. The area supplies much of the United States winter produce, in particular lettuce, and also produces much citrus, field crops and livestock. Currently agriculture in Lower Colorado River has sufficient land and water to thrive but it is also potentially threatened in the future by urbanization and water supply and water quality issues. Each of these issues is discussed below with regards to their effects on the long term sustainability of agriculture in the Lower Colorado River area.

Urbanization

Urbanization, as used herein to generically describe the increase in non-agricultural land uses including residential, commercial and industrial land uses and their associated water use demands, is having and will continue to have an overall significant impact on agricultural lands along the Lower Colorado River. The effects of urbanization on individual irrigation districts in the area will vary greatly, from having almost no effect to having a very significant impact on agriculture.

It is not anticipated that urbanization will have a significant impact at all in the Bard Water District or in the North Gila Valley Irrigation District. There are very little existing urban land uses in these districts now and both have farm economies that are presently profitable and are expected to remain that way. Neither area has much in the way of urban infrastructure, and while the Quechan population in the Indian Unit of BWD will continue to grow, the overall land use of such growth should be relatively minor. In addition relatively high groundwater levels in both valleys and lack of certified flood control levees in the North Gila Valley are detriments to any large scale developments.

The irrigation districts on the Yuma Mesa, YMIDD and Unit B, are probably most at risk due to urbanization. YMIDD will most likely continue to see increases in urbanization in the north end of the district as the City of Yuma grows and it will see increased development of ranchettes as long as zoning rules stay the same. As YMIDD does have the ability to expand the District's boundaries to the south (provided the City of San Luis does not grow too quickly to the north), irrigated agriculture can expand away from the northerly development provided that the irrigation delivery infrastructure can be extended economically. At some point in the future though, whether it is 25 years or 50 years or more from now, the reality of YMIDD being in the path for urban growth will be realized and it can be projected that YMIDD will be mostly urbanized. For water right purposes, the ability for YMIDD to convert their agricultural water rights to M&I water rights will need to be maintained and potentially exercised.

The urbanization of Unit B is in some ways well along at present with the existing development of the residential ranchettes. The remaining cultivated lands will over time come under pressure for further development, either as additional ranchettes or as higher intensity uses such as industrial use. The City of Somerton has expanded its corporate boundaries to Unit B and the adjacent East Cocopah reservation is also developing and so over time it can be anticipated that commercial agriculture in Unit B will be minimal, though small scale agriculture on the ranchettes will continue.

The valley districts to the east and south of the City of Yuma, Yuma Irrigation District and the Yuma County Water Users' Association, will both face urbanization but with significant agricultural infrastructure in these areas based on the profitable produce crops grown in the valleys, the pace of urbanization should be more moderate. Urbanization of these valleys will also be somewhat slowed by land use planning currently favorable to agriculture and by the generally higher cost of urban land development in the valleys due to high groundwater tables and poor soils for infrastructure. Generally it can be said that urbanization of these valleys will be gradual as long as farming in the valleys remains profitable.

For the Wellton-Mohawk Irrigation and Drainage District, present day urban development is limited almost fully to the mesa lands around the towns of Wellton and Tacna. Very little development occurs in the Gila River valley area and as long as protection from flooding remains an issue, little future development in the valley area should occur. Future development of the mesa lands in and adjacent to WMIDD should be gradual for the near future but at some point – for example after growth from the Yuma side of the Gila Mountains moves east or if a significant development project (such as a now proposed oil refinery) becomes reality – growth could become rapid. With regards to current farm economics, the mesa lands are currently the least profitable, being in citrus and hay primarily, while the valley lands are more profitable with their produce crops and so one would expect the valley lands to be the last to be developed.

Water Supply Issues

The Colorado River is one of the most heavily used rivers in the United States, and in fact is in most years fully diverted for water supply to the various states along its length. Much of the last century has been spent in developing compacts and agreements (the "Law of the River") governing use of Colorado River water and it can be anticipated, especially in times of shortage, to see continued negotiations and litigation in the future.

The Colorado River is an interstate and international river, and as such, it use is regulated by both federal agencies, primarily the U.S. Bureau of Reclamation (USBR), and by the states. Water rights for Colorado River water are a combination of federal and state rights, with the states having limits as to how much water they can use in total and regulating the use within the state and with the USBR entering into water right contracts with individuals and public entities. The USBR acts as water master for the river and is closely watched by the states and other federal agencies.

<u>Irrigation District Water Supplies</u> The irrigation districts in the Lower Colorado Region have in general senior water rights. Colorado River water rights are given priorities of 1

through 6, with 6 being the junior rights. The seven irrigation districts discussed in this paper generally have either priority 1 (present perfected rights) or priority 2 or 3 rights (contracted prior to 1968 and co-equal to each other).

While good water rights are of first importance in having a secure future water supply, good stewardship of the water that is used is also critical. Colorado River water must be put to beneficial use. The standard of what is beneficial, however, changes over time and especially changes in times of water shortages. As large metropolitan areas such as Phoenix, Los Angeles and Las Vegas enact ever more stringent water conservation measures in order to stretch their water supplies for their growing populations, it becomes politically difficult to not show water conservation efforts in the use of water for agricultural purposes.

Overall, while the irrigation districts in the study area have some of the best water rights on the Colorado River, they must also be prepared to defend those rights through good stewardship of them in order to keep them sustainable.

Non-Irrigation District Water Supplies The other users of Colorado River water in the study area have various quantified and unquantified water rights that have varying levels of problems with their long term sustainability.

The City of Yuma is the largest non-agricultural water right holder, with some present perfected rights and the remainder of their rights priority 3. There are also about 8000 acre-feet of priority 2 and 3 water right holders, most of these being either small agricultural acres outside of the irrigation districts (with the Gila Monster Ranch in the North Gila Valley being the largest of these) or else municipal water users such as cemeteries and schools.

Priority 4, 5 and 6 water right holders include the Cocopah Indian Reservation and about 10 smaller contractors, including the City of Somerton and various M&I and agricultural users.

Unquantified water right holders and those water users without water rights are primarily the groundwater pumpers along the Colorado River (especially on the Yuma Island adjacent to Bard Water District) and those with groundwater wells on the mesa lands and in other area. It should be noted here that water use in the Gila River drainage area is not a part of the Colorado River apportionment of water. No Colorado River water rights are required for use of groundwater or Gila River water in the Gila River drainage area (which is essentially in the WMIDD area.)

The long term sustainability of non-irrigation district water supplies in the study area is a function of the priority of the existing water rights, if any, and the use of the water, whether for M&I purposes or for agricultural purposes. In general, the M&I water users benefit from the long term use that M&I water is put to once it is put to use, i.e., on farm water use of course has significant infrastructure built to support it but at the same time its use can often be curtailed for a season in times of shortage, whereas water put to use to directly support say residential development must be used continuously as long as the residential development exists. Therefore it is expected that users such as the cities of Yuma, San Luis, Somerton and Wellton will, due to the nature of their water use, be able to count on long term water supplies regardless of their water right priorities. Even the City of San Luis, which now relies almost exclusively on unquantified groundwater rights, should be able to exercise its rights for the foreseeable future (while the City of San Luis pumps Colorado River water, if they did not that water would be pumped by Mexico and lost to the United States.)

The greatest threat to long term sustainability of water supply in the Lower Colorado River region is probably to those users of Colorado River water that either do not have a water right (primarily those that pump groundwater) and those users that do not exercise their rights. Much study of the source of groundwater in the study area has been conducted in recent years by the U.S. Geological Survey and the U.S. Bureau of Reclamation for the ultimate purpose of further regulating the use of subsurface Colorado River water and ultimately curtailing its use without water right contracts.

Thus it can be said that long term sustainability of water supplies for irrigated agriculture outside of the irrigation districts will be subject to increasing legal scrutiny in the coming years. With that said, the argument can be made that groundwater use may have no greater consumptive use than native vegetation in the valley areas (where native vegetation is plentiful) but it is thought that eventually groundwater pumping without a Colorado River water right contract could be substantially curtailed. Those water users with water right contracts should have a better time defending their usage, but as discussed above, should still strive to improve their stewardship of the water that they use.

Water Quality Issues

As stated at the beginning of this paper, the water use in the Lower Colorado River area is primarily 'run-of-the-river', meaning that water is diverted from the river as water supply and water is returned to the river as return flows. As such, as long as adequate return flows exist their can be something of an equilibrium existing in water quality. Salts and other water quality constituents are concentrated due to evapo-transpiration during application and flushed to some extent as soils are drained.

The Colorado River has high total dissolved solids (TDS) levels upstream of the study area due to both naturally occurring flows and due to upstream agriculture and other water uses. With the additional return flows and salinity added in this area, water quality became a major concern of Mexico's in the 1960's and the treaty between the United States and Mexico was amended to include water quality criteria for delivery of Colorado River Water to Mexico. While water quality had long been a concern of Mexico's, the 1960's saw the completion of the Gila Project and especially the increase in return flows from lands formerly irrigated by well water (with irrigation by well water essentially recycling groundwater supplies, increasing the salinity incrementally over time with each reuse.) Much of the new drainage from the Gila Project lands, especially from the

Wellton-Mohawk area, where wells were extensively used for a long period of time, was diverted in a separate drainage channel, around the South Gila and Yuma Valleys to Mexico near the delta of the Colorado River at what is known as the Santa Clara Slough.

Since the 1960's water quality of return flows, as measured by TDS, has been fairly constant and in some areas, such as the WMIDD drainage flows, have actually improved as previously accumulated salts are leached out. Groundwater quality from shallower wells (less than about 200 feet) is essentially the same as return flow quality but depending more on the recharge source, whether from deep percolation from agriculture or from recharge by river flows. Deeper wells often produce better quality if water unaffected by agriculture is pumped, though the local soil formation can have significant negative effects on the quality.

The sustainability of the current water quality levels in the area depends to a great deal on maintaining the current status quo of water deliveries, groundwater usage, and groundwater recharge. Increases in groundwater use for agriculture, whether caused by declines in surface water deliveries or simply increases in overall water use, will cause increases in TDS as the more saline groundwater is applied to the land and further concentrated.

Similarly, decreases in groundwater recharge due to river flows will result in increased salinity as the river flows, whether from the Colorado River or Gila River (except those flows from the Gila that are subject to significant evaporation as Painted Rock Dam is drained) are of lesser TDS content than agricultural percolation.

Water Conservation and Environmental Issues

The generally accepted concept is that water conservation is beneficial to both the manmade environment and to the natural environment. For example, to the extent that water conservation reduces water logging of agricultural lands, such water conservation is beneficial to the manmade environment. Similarly, if water conservation increases in-stream flows by reducing diversions, such is also beneficial to the natural environment. Water conversation by definition affects an areas water balance and as such it affects the sustainability of water use in an area.

In the Lower Colorado River Region, however, water conservation, whether locally or outside the region, can have negative effects. Potential water conservation practices and their potential effects on the region include the following.

- Increases in on-farm water use efficiency, resulting in less deep percolation of irrigation water. To the extent that crop production is increased, this can benefit the area. To the extent that less water is recharged but with the same salt level, the effect is to increase the TDS of groundwater and return flows, thus lowering their usefulness.
- Increases in on-farm and delivery system efficiencies, resulting in a decrease in return flows to agriculture drains and a decrease in operational

discharges from canal systems. These conservation measures decrease base flows in the Colorado River and Gila River channels (especially the Gila River in the WMIDD area, as return flows are typically its only water supply, thus keeping the riparian area alive.)

- Better operation of the mainstream Colorado River delivery system such as to reduce inadvertent over deliveries to the Yuma area results in less flows released below Morelos Dam and less groundwater recharge in the limitrophe section of the Colorado. Thus groundwater pumping will further lower the groundwater table, reducing the areas of wetlands and riparian vegetation that depend on groundwater.
- Increased upstream water storage capacity resulting in less frequent flood events on the Colorado and Gila Rivers. Especially on the Gila River, the long duration floods that occur now about every 10 years or so result in significant groundwater recharge of aquifers along the river. Reduction in that recharge would result in the overall lowering of the groundwater table and loss of riparian wetlands and vegetation. Similar effects would occur in the limitrophe section of the Colorado.

Also a water conservation issue is the operation of the Yuma Desalting Plant (YPD). The YDP was constructed to improve the quality of Colorado River water delivered to Mexico by desalting drainage flows from the WMIDD drains. Since its construction, however, the drainage flows have been delivered to the Santa Clara Slough in Mexico, creating a significant wetland there. Future operation of the plant, which will increase available Colorado River Water for lower priority users, will result in decreases in the size of the Santa Clara Slough (though there are arguments that not all of the water delivered to the Slough is needed.)

Overall, water conservation efforts affecting the Lower Colorado River have the potential to reduce the sustainability of agriculture in the area. While possibly counter-intuitive, the present status quo of the area can be characterized as very water rich environment (it is near the delta of a major river system). Continued water conservation will reduce flows to the agricultural drains, resulting in a new groundwater regime which will show up as diminished riparian areas and as degraded groundwater quality.

SUMMARY

In the area between the Imperial Dam and the Mexican border along the Lower Colorado River, the existing uses of Colorado River water for irrigated agriculture has allowed the development of some 160,000 acres of farmland. The seven irrigation districts in area along with the irrigated areas outside of the irrigation districts are presently in a sustainable mode, having operated in much the same way since their development, beginning in early 1900's and into the 1960's.

With increasing basin wide demands being placed on the Colorado River's resources and with the urban growth occurring in the study area, the current status quo of water use will change in the future. While maintaining the status quo would be preferable for most all water users and the environment (though perhaps with alleviating drainage problems in some areas of excess groundwater), if such cannot be maintained then awareness of the changes and appropriate planning may mitigate changes to the area, allowing irrigated agriculture to thrive for many years into the future.

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IRRIGATION AND WATER DELIVERY IMPROVEMENTS USING WIRELESS COMMUNICATION TECHNOLOGY

Dan Paladino[1]

ABSTRACT

Radio communications and their advanced flexibility offer technological benefits to new SCADA system deployment as well as a means for upgrading performance to existing SCADA systems. In fact, the limitations and cost of wired systems can be eliminated. Improvements in radio technologies now allow for innovative control and monitoring of SCADA systems thus providing users the ability to more reliably monitor and control devices from a distance. Points within an irrigation system can be brought to a user's fingertips without the expense of running wire or fiber to remote locations. Licensed and unlicensed radios can work in coordination to offer the speed and security to build robust professionally designed SCADA networks. The addition of radio communications to field installed devices or newly deployed systems with RF can prolong the usefulness of existing equipment and ensure years of reliable SCADA network operations. Radio communications offer the flexibility to expand communication capabilities to meet the ever-expanding requirements of fast-growing, high data service areas and SCADA operations.

This presentation will educate and reinforce how wireless radio systems can provide a reliable communication backbone for all of an irrigation organization's analog/digital (I/O), serial and Ethernet challenges.

INTRODUCTION

<u>Save Water, Preserve Resources, Reduce Consumption and Improve Productivity</u>

These are the 100 year mandates that have been presented to us. The challenge ahead is daunting to say the least. Our collective goal is to do more with less; less water, less land, and less labor. In order to accomplish these goals we need to find ways to improve upon our current methods, processes that we have perfected over many, many, many decades. To improve our processes and to achieve success in meeting our goals we need to introduce new technologies into our daily activities and operations.

Our nation's farms and irrigation districts are losing access to water because the world's population is booming and our cities are expanding. At the same time our growing need for food requires that we increase our crop yields to meet the ever increasing demands of the world's population.

Today, we have numerous technologies at our fingertips that can assist in meeting future performance expectations. One simple word that describes these technologies is

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"automation." The same automation that has created information superhighways and has allowed for reduced cost and higher productivity in producing fuels can also be used within the irrigation industry. We must aggressively integrate proven automation methods to meet our specific needs and operational requirements. Some of the available technologies include communication and control improvements. Examples are wireless communication, automated controls, and automated sensors. Each of these technologies is capable of reducing the use of and waste of our water resources. Admittedly, any installation of automation has a price tag, sometimes hefty. It has been proven over and over that the return on investment more than pays for the initial cost of installation of the automated technology improvements in relatively short timeframes.

Automation can be used as we deliver water from one location to another. At each step and function in our water deliver infrastructure we need to consider what options are available to improve our systems. The introduction of automation will allow us to save our way to future demands of our resources. By reducing consumption and loss and by improving our techniques we prolong the useful availability of our streams and rivers, our aquifers, and our reservoirs. In short, we improve our ability to survive the threat of population growth.

Irrigation is a prime example where the integration of automation can result in enormous cost and resource savings. Introduction of an automated systems share a common theme…communication.

Figure 1. Irrigation Pipes

It is essential that a communication network be defined prior to total deployment of automated equipment. Without a robust communication infrastructure to control equipment or gather data (SCADA) the most advanced equipment is left under utilized.

A comprehensive network will allow for district or operation wide communication and/or control. By establishing a reliable communication network which covers the entire service area you allow for unlimited improvement to your processes. This communication network will be the backbone of the entire automation process.

First, it is important to understand the differences and limitations of each available wireless technology. There are landline, cellular, satellite, short-range wireless, long-range wireless, non-licensed or licensed networks, serial and Ethernet, analog or digital. Each of these technologies has positives and negatives as well as limitations. It is up to you to determine what technology or combination of technologies will give you years of reliable operation. In order to determine this you need to establish what you want to accomplish starting today and ending with a completely automated control system (SCADA). Be prepared, sometimes the best network is a 'hybrid' combination of more than one technologies.

Radio controlled systems have been used for decades in almost every industry worldwide to improve efficiencies and to reduce costs. The initial investment in establishing and installing a wireless network can often be recouped through fuel saving and employee overhead / task optimization.

Additionally, recouping initial installation costs will take place as water savings are recognized. It is also possible that saved water can be redeployed to assist in providing additional water to growing metropolitan areas.

Figure 2. Irrigation Turf

Wireless Technologies

As mentioned wireless technologies will be the first and most important aspect of your automation efforts. Therefore, you will need to address the short- and long-term requirements of your network during the early stages of your planning and review process. The first step is to determine how and where you can use wireless.

It is a growing trend to move to a non-licensed radio that allows for continual growth without the restriction or limitation of applying for and owning an FCC operation license. This leaves a very robust ISM (900MHz or 2.4GHz) radio system. These are non-licensed radios that allow for long range, flexible use. ISM or non-licensed radios allow you to use Ethernet backbones with smaller sub-networks "hanging" from the backbone. These sub-networks can be serial (using Mod-Bus or similar protocols) to address each endpoint device. The devices can be controllers, center pivots, or other like devices that actually controls the release of water. It is also possible then to have sensors (moisture detection, flow meters, water levels, weather monitors, etc) installed throughout the operation connected to your network using simple analog or digital (4-20mA or 1-5V) connection.

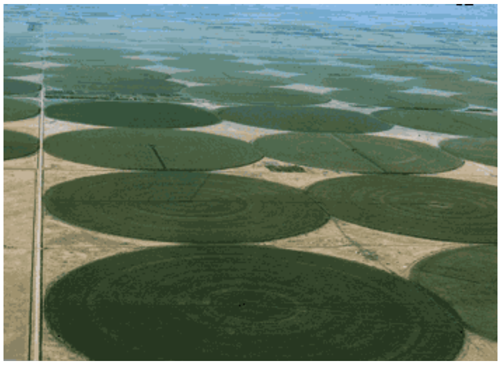

Figure 3. Pivot Irrigation

By establishing this network you have now created a communication and control system that can control flows, establish diversion paths, view performance characteristics and monitor each specific sensor to help determine proper watering patterns throughout your entire service area.

ISM Radios

These radios are available to end-users without the need to apply for or acquire a user license from the FCC. The certification of ISM radios is obtained by the manufacturer and is then assigned to each radio as it is manufactured.

ISM radios are radios that fall into 3 common frequency bands commonly referred to as 900MHz, 2.4GHz, or 5.8GHz. The most frequently used technology used in the U.S. is 900MHz. The 2.4GHz band is used outside the U.S., but is not necessarily approved for use in every country. Please note that 2.4 GHz can also be used without exception in the U.S. as well. Each of these 900MHz radios can/will utilize the entire 902-928MHz band by searching for available channels via ‘hopping’ within the frequency band in search of an open channel. When an open channel is found the radio automatically sends and receives the message or command.

Figure 4. Wireless radio

There is a significant difference in radio technology. Many radios are designed to hear loud, clear signals and they operate best in low noise areas. Others radios are designed to hear “quiet” transmission in a noisy area. This difference is what can separate a decent radio from a great radio. It is important to realize that there are a few additional key characteristics inherent in each radio that help determine its ability to operate reliably in all/most conditions. These key characteristics are not the sole performance capabilities that make a radio perform well but they are very important as you begin your search. Always look at a radio’s sensitivity (don’t get excited simply by published datasheet specifications), ‘hopping speed,’ and ability to avoid interference. These three characteristics will eliminate many lesser performing radios as you begin your search. It is very important to not underestimate the importance of these characteristics because every location has radio frequency (RF) noise in the area. Noise is generated from other RF devices in the area (sometimes from devices installed 20-30 miles away). A good radio will be able to separate/ignore noise from other radios/systems and focus only the signal from your system.

The next crucial step is to test radios in real world situations, not just in a laboratory setting. Laboratory settings generally provide optimal conditions where noise or interference is reduced. Field or pilot testing will show how well a radio will perform when unexpected conditions present themselves.

As you perform/install your pilot, test the radio's flexibility by creating sub-networks by pre-determining signal paths, by calculating and creating situations where you have heavy traffic which will simulate potential overloading of a network. Also, make sure you attach the radio to current equipment in the field. You will do this to determine if the radio can speak with multiple protocols or can work with multiple devices manufactured by different vendors. You also want to install radios at the furthest points of your service area to determine proper coverage. If a particular radio can not communicate all the way back to the 'master' you will want to determine if the radio vendor you are using will allow you to use a like radio to act as a repeater. Ideally, any repeater radio will also allow for an additional device (multiple ports) to be connected. This will help reduce the total number of radios being installed and ultimately your system cost.

There are many crucial aspects to a field pilot study and failure to do a proper field study can result in a underperforming disappointing system. There is no 'cookbook' that works in all situations so it is important that you establish specific criteria that accurately represents the goals of your ultimate communication network.

SUMMARY

In summary, there are a many modifications that can save enormous amounts of water, improve efficiencies within systems and decrease the total amount of water being used. The starting point to improving any operational irrigation system is to improve the communication and control backbone of these systems.

It is possible to establish full automation into the processes of irrigation within the area being served. The use of a performance appropriate wireless network is mandatory in operating a system that is capable of controlling and monitoring district wide performance. By installing a wireless network, real time data or control can be managed from a central location with minimal human interaction. The communication network will provide the range and flexibility to reach each and every device required to improve the overall performance of your perfect SCADA system.

PAST, PRESENT, AND FUTURE: UINTAH WATER CONSERVANCY DISTRICT'S STRATEGY TO MEET WATER CHALLENGES

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ABSTRACT

Over the past few decades, plans to increase the water supply for irrigation in the Uinta River Basin have not materialized. Because of this, the Uintah Water Conservancy District (UWCD) is looking at the big picture when it comes to sustaining the irrigation water supply in western Uintah County, Utah. By taking advantage of the synergy of projects past, present, and future, the water supply from two river systems is being used and managed more efficiently.

Past: The West Side Combined Canals Salinity Project (Combined Canals) is a unique combined irrigation project which replaced 46.4 miles of 7 canals with one diversion structure, 15 miles of main transmission pipeline, and 21 miles of laterals.

Present: The Green River Pumping Project (GRPP) will develop 8,500 acre-feet of Green River water for supplemental irrigation. With the implementation of the GRPP and use of the Combined Canals facilities, use of water from the Uinta, Whiterocks, and Green Rivers will be optimized through a water exchange.

Future: UWCD is collaborating with the Duchesne County and Central Utah Water Conservancy Districts to establish a basin-wide water development project known as the Green River Exchange Project. The Districts have investigated the potential for combining upstream storage on the Uinta River with pumping from the Green River to make further water exchanges possible.

INTRODUCTION

District Description

The Uintah Water Conservancy District (UWCD) was established in 1959 to develop and conserve water supplies for the benefit of Uintah County inhabitants and to construct, operate, and maintain facilities associated with these water resources. For many years, UWCD's main focus had been the management of the Vernal and Jensen Units of the Central Utah Project (CUP), which include Steinaker and Red Fleet Dams. These facilities serve mostly the eastern portion of UWCD's service area.

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The western portion of the District covers the Uinta River Basin. In recent years, UWCD has been more involved on projects in this area. The District's involvement on such projects illustrates a commitment to the sustainability of irrigation districts by envisioning new types of projects, utilizing new sources of water, collaborating with irrigation companies and water conservancy districts, and changing the outlook on water marketing.

Problem Definition

Irrigation Need There has long been a need for water development in the Uinta River Basin. The Uintah Unit of the Central Utah Project (CUP) was originally planned to develop flows primarily for irrigation purposes. Though the first feasibility study for the Uintah Unit was completed in 1968, the project was never realized. In 1991, the Central Utah Project Completion Act (CUPCA) was passed. Understanding the need for water development along the Uinta River, this act essentially provided one more chance to develop a replacement project for the original Uintah Unit. Unfortunately, due to failed negotiations with the Ute Tribe, the Uintah Basin Replacement Project, as defined in a 1997 feasibility study, was never implemented. Water shortages continue to exist on the agricultural lands, and the fact that a water development project along the Uinta River was never built, does not alleviate those shortages. Over the years, as plans for the Uintah Unit and subsequent replacement projects were dissolved, the need for water has increased.

Green River Allocation Another result of CUPCA legislation was the de-authorization of the Ultimate Phase of the CUP, which was basically the project concept of delivering water stored in Flaming Gorge Reservoir to Utah's Wasatch Front. When the Ultimate Phase of the Central Utah Project was dissolved, the U.S. Bureau of Reclamation was left with a 430,910-acre-foot storage filing in the Flaming Gorge Reservoir, located on the Green River. The Utah Division of Water Resources was given control over the water right in order to preserve the 1956 priority date. They have since segregated the water right to conservancy districts, irrigation companies, and individuals for beneficial use. In 1999, UWCD was allocated 51,800 acre-feet (acft).

Shift in Water Demand Due to the growing energy industry, UWCD is witnessing a changing demand for water resources. With the potential for oil development in the Uintah Basin, the population is expected to expand at a greater rate than the historical average. By 2050, the municipal demands are estimated to more than triple. Since water is needed to develop oil, the annual water demand for production from oil shale and tar sands could be 100,000 acft (FCE and CH2MHill 2007). Because of this, UWCD foresees the need of not only being able to provide water for irrigation, including shortages, but also to supply water for these various municipal and industrial water demands.

Strategy

In response to the issues defined above, UWCD is looking at the big picture when it comes to sustaining the irrigation water supply in western Uintah County. By taking advantage of the synergy of projects past, present, and future, the water supply from two river systems is being used and managed more efficiently.

The first step taken by UWCD was to make existing systems more efficient. This included converting aged earthen ditches to pressurized pipelines, and therefore, increasing their supply through conservation. Next, UWCD explored new sources of water in order to supplement shortages and return some lands to production with a full supply. The final aspect of UWCD's strategy to meet water challenges was to coordinate with other conservancy districts to investigate basin-wide projects that would realize the goals of the CUP.

WEST SIDE COMBINED CANALS SALINITY PROJECT

Description

Over a decade ago, an irrigation company in western Uintah County received funding from the Colorado River Basin Salinity Control Program (CRBSCP) to pipe their canal. When the irrigation company requested assistance, UWCD realized the potential for other companies to receive similar benefit. The West Side Combined Canals Salinity Project (Combined Canals) was born. The result was a multi-million dollar combined irrigation project that met the needs of two irrigation companies and the Ute and Ouray Indian Tribes. The Combined Canals was constructed in phases between 2000 and 2008. In total, the project cost just over $14 million.

UWCD assisted the Ouray Park and Uintah River Irrigation Companies (OPIC and URIC), and the Bureau of Indian Affairs (BIA) in implementing the one of a kind combined irrigation project. The Combined Canals, which serves over 14,000 acres, consisted of replacing 46.4 miles of canal with a 200-cfs diversion structure from the Uinta River, rehabilitation of the Cottonwood Reservoir outlet works, 8.3 miles of 48-inch diameter HDPE pipe, almost 7 miles of other large (24-inch to 36-inch) diameter pipe, and 21 miles of laterals.

In order to accomplish a project of this magnitude, coordination with several agencies, including the U.S. Bureau of Reclamation, was necessary to obtain funding and establish environmental and ecological benefits. UWCD also facilitated the implementation of water use agreements and operation and management tools, including an extensive SCADA system, to ensure the success of the Combined Canals.

The Combined Canals is a good example of the benefits that can result from looking at the bigger picture of an engineering project. By combining the various canal replacement projects, water conservation was achieved at a lower cost. Also, salinity contribution to the Colorado River system was reduced at a more efficient rate. Since the salt loading from several canals was reduced with one large project, which was less expensive than several smaller projects, more CRBSCP funding was available to other salinity reduction projects.

This project, shown in Figure 1, demonstrates three methods of increasing the sustainability of irrigation districts, namely, coordination, conservation, and technology.

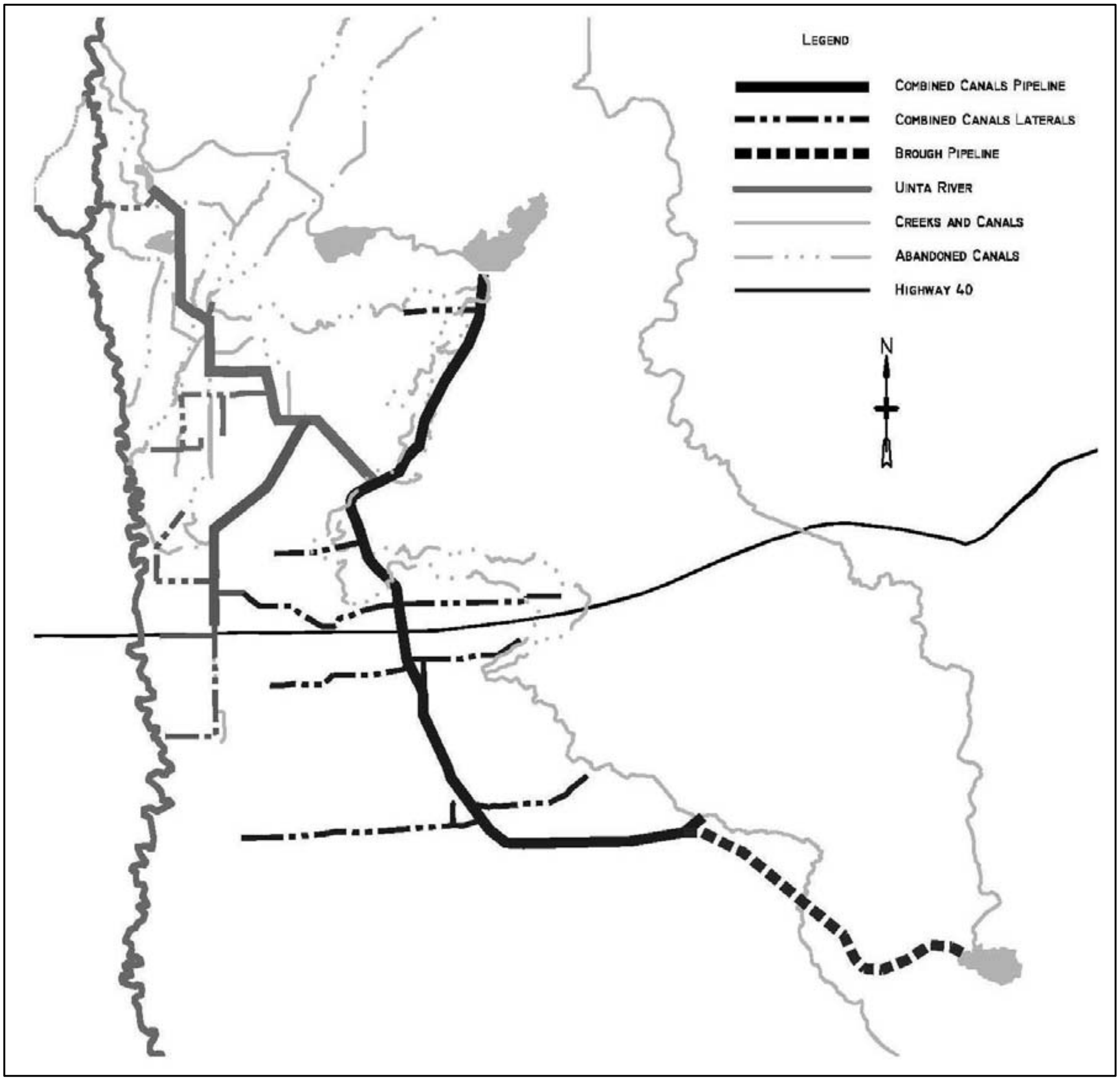

Figure 1. West Side Combined Canals Salinity Project

Coordination

Before conception of the Combined Canals, the seven canals were owned and operated separately by two irrigation companies and the Ute and Ouray Indian Tribes. 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 Combined Canals to be successful, the irrigation companies and Tribes would have to work together to overcome many obstacles, all while achieving a technically innovative and socially acceptable design. The four major obstacles included obtaining project funding, satisfying environmental and ecological requirements, juggling water rights, and easing historical mistrust (Ploeger and Andrew 2004).

The project's non-technical challenges were overcome thru coordination with the U.S. Bureau of Reclamation to obtain funding from the Colorado River Basin Salinity Control Program, compilation of several water use documents to define operation and management of various project facilities and water rights, and installation of an extensive SCADA system to implement the water use agreements.

The Combined Canals would not have been possible without the input from the project participants. One of the first steps of the project planning was to create a steering committee made up of representatives from UWCD, OPIC, URIC, and BIA. This group met monthly over the past decade to oversee and direct the development of the Combined Canals. They compromised and agreed to a memorandum of understanding and other water use agreements that defined the operation of the project. The committee also helped to make critical design choices presented by the engineer.

Conservation

BIA, URIC, and OPIC had historically competed over the limited Uinta River water supply. Through the implementation of the Combined Canals, these entities realized that by working together thousands of acre feet of water could be conserved. By combining the various canal replacement projects, water conservation was achieved at a lower cost. Each entity was able to realize an increased water supply that may have been economically infeasible had they tried to implement an individual project.

Over 46 miles of canals were converted from open ditches to a pipeline distribution system. The water supply is extremely limited in the area and thus the resulting increase of water due to the saved water has significant economic benefits to the irrigators. The estimated amount of water conserved by the Combined Canals is over 11,000 acft/year. This amounts to approximately 25% of the annual supply.

Technology

The idea of a combined system was innovative because not only water, but also water rights and system operation, would be commingled. Having historically competed over a limited Uinta River water supply, people were not eager to participate. In order for the

Combined Canals to succeed, system operation would need to ensure the honoring of existing water rights. A detailed Memorandum of Understanding was negotiated and an extensive Supervisory Control and Data Acquisition (SCADA) system was implemented to allow the project participants to monitor water usage and water accounting. A SCADA system is usually thought of as just an operational need, but here it was absolutely critical.

The project was planned, designed, and constructed to use the latest in water measurement technology to allow for accurate water accounting. The measurement of water and accounting by user assures that the use of water is within the parameters of the original water rights. The extensive use of meters in an agricultural setting is an innovative but critical part of the success of this project (Franson, Ploeger, and Hogge 2009).

While the water accounting is critical to the operation & success of the project, the project also uses the capabilities of SCADA by allowing remote operation at 6 critical points within the system. Due to the remote location of these points, some of which are accessible only by unimproved roads, travel times are measured in hours.

GREEN RIVER PUMPING PROJECT

Once the Combined Canals was nearing completion, UWCD shifted its focus to the Green River Pumping Project (GRPP). UWCD is currently transitioning between the design and construction phases of the GRPP.

Description

The goal of the Green River Pumping Project (GRPP) is to develop Green River water for agricultural purposes on the west side of Uintah County. The project is shown in Figure 2. The GRPP will provide supplemental irrigation water to the Ouray Park and Uintah River Irrigation Companies (OPIC and URIC, respectively), and potentially to the Whiterocks Irrigation Company.

The project will include a pump station on the Green River. Water will be pumped through a new pipeline to a pond located above the existing Ouray Park Pipeline (OPP). The pond will be connected to the OPP and will provide pressure and limited storage capacity. Some limited storage capacity in the pond will allow the pumps on the Green River to be operated during off peak electrical periods, thus reducing the pumping costs. Water pressures at existing turnouts will be no less than under present conditions.

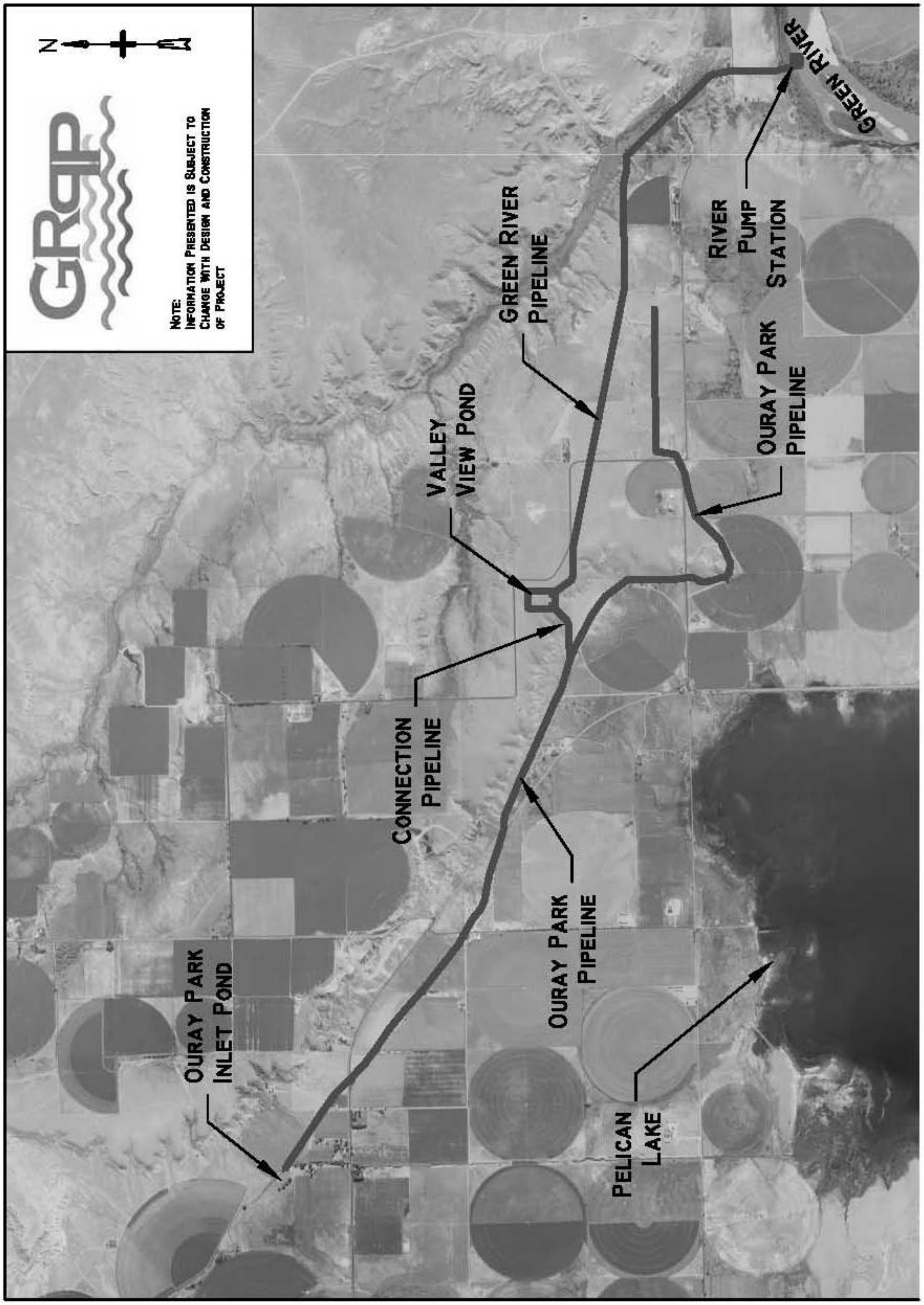

Figure 2. Green River Pumping Project Facility Map

Water Exchanges

The key to the GRPP, and what shows that UWCD is willing to think outside the box with respect to water challenges, is the concept of water exchanges.

Water for the GRPP will come from three sources: namely the new source, the Green River; and the two existing sources, the Uinta and Whiterocks Rivers. The Green River water is a portion of UWCD's 51,800 acft allocation of the Flaming Gorge water right. The currently proposed GRPP facilities will develop at least 8,500 acft of UWCD's Green River water allocation.

Currently, the Uinta and Whiterocks Rivers provide water to the OPIC and URIC service areas. With the implementation of the GRPP, use of water from the Uinta, Whiterocks, and Green Rivers will be optimized through a water exchange. The water exchange concept for the project, illustrated in Figure 3, is as follows:

- The water typically delivered to OPIC's Cottonwood service area will be replaced by water pumped from the Green River.
- The water that would typically have been delivered to the Cottonwood service area from the Uinta and Whiterocks Rivers will be delivered (by exchange) to the URIC service area and OPIC's Brough service area to supplement their supply.
- Additional water pumped from the Green River will also provide supplemental water to OPIC's Cottonwood service area.

Synergy

The GRPP will be integrated with two existing pipelines: the Ouray Park Pipeline (OPP) and the Brough Pipeline. The OPP replaced about 25,000 feet of the lower Ouray Park Canal. It currently delivers Uinta River water to lands that could be directly served by the GRPP, namely OPIC's Cottonwood service area. The Brough Pipeline is an extension of the Combined Canals, construction of which is currently being completed in the spring of 2009. The Ouray Park and Brough Pipelines will be operated in conjunction with the proposed GRPP facilities to maximize the delivery efficiency and benefits of the project.

The completion of the Brough Pipeline will allow UWCD to deliver water from the Whiterocks River through the Combined Canals to Brough Reservoir during 11 months of the year. This will result in the abandonment of the Ouray Valley Canal for those 11 months and additional water savings of approximately 1,000 acft/year.

Though the Combined Canal Project and the GRPP are separate independent projects, they are integrally connected since they involve the same participants and agricultural lands. Each project compliments the other.

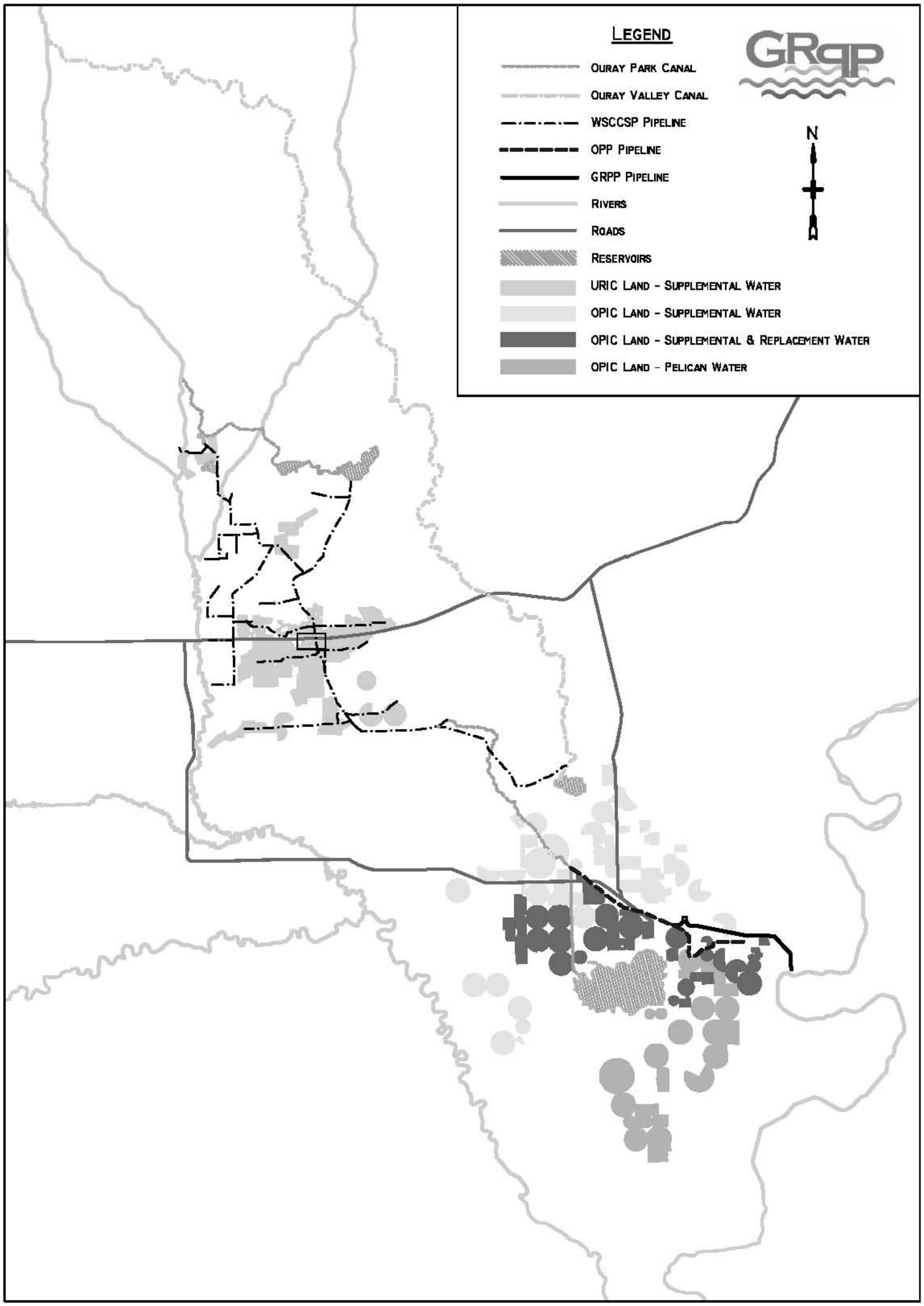

Figure 3. Green River Pumping Project Exchange Areas

It is important to recognize that these projects could be viewed as an alternative to the Uintah Basin Replacement Project (UBRP) that was never built. These projects will achieve the same ultimate goals through different means. Some of the similarities between the two projects are as follows:

1. Combined diversion for the Moffat and Ouray Park Canals.
2. Alternate method for delivering water to Brough Reservoir.
3. Increase in delivery efficiency.
4. Increased water supply distributed throughout irrigation season.

GREEN RIVER EXCHANGE PROJECT

Background

As stated above, there has long been a need for water development in the Uinta River Basin. Over the years, as plans for the Uintah Unit and subsequent replacement projects were dissolved, the need for water has increased. Presently, there is a need to manage the water supply in eastern Duchesne and western Uintah Counties to provide early and late season irrigation water and provide water and facilities for a rapidly growing population and oil field industry, as well as for environmental and recreational purposes.

UWCD, along with the Duchesne County Water Conservancy District (DCWCD), have envisioned the use of their Green River allocations to meet those needs. In addition to the 51,800 acft allocated to UWCD, DCWCD was allocated 47,600 acft of Green River water. Together, the two districts have the opportunity to develop 99,400 acft

Coordination

Each of the districts that cover parts of the Uinta River Basin, DCWCD and UWCD, have recognized the need for both agricultural and municipal and industrial (M&I) water development. Over the years, both districts investigated the feasibility of projects that could increase their water supply. When Flaming Gorge water rights became available out of the Green River, both districts applied for an allocation. As work moved forward on individual water development projects, managers and trustees of both DCWCD and UWCD realized the need to work together to successfully implement a project that would be beneficial basin-wide.

DCWCD and UWCD then solicited help from the Central Utah Water Conservancy District (CUWCD) to develop a project plan that would meet the needs of water users throughout the Uinta River Basin. It became obvious that developing a successful water project was not a matter of political subdivision, i.e. counties or conservancy districts; but a matter of water users throughout the river basin needing water for growing populations and changing needs. Therefore, the three districts have come together to develop a basin-wide project concept.

Potential Projects

The three districts have collaborated on investigating the feasibility of various projects. Several reports have been compiled that document what has been done to date regarding water development, explore potential reservoir sites, and model existing and potential water demands against the available and developable water supplies.

One study involved identifying and developing scenarios for evaluation. Ten scenarios were identified and developed. Each scenario was made up of different combinations of proposed project features. These project features include the following:

- four proposed reservoir sites (one on-stream and three off-stream),
- two proposed enlarged reservoirs,
- an extension of a feeder canal from the Yellowstone River,
- pumping from the Green River, and
- multiple water right exchanges.

UWCD and DCWCD are also heavily investigating opportunities to market some of their Green River allocations to the oil industry. Both districts have had applications to segregate portions of their rights for industrial demands. As of December 2007, 10,590 acft have been requested, of which 4,230 acft have been segregated.

Current Status

The most important result of the above-mentioned studies is that the districts have secured their respective Green River water rights from Board of Water Resources. As public entities that are planning for the future needs of their citizens, they are not in danger of forfeiting the rights due to non-use. This will give the districts ample time to formulate the most feasible and cost effective project, obtain funding, and implement a project that will benefit water users throughout the Uintah Basin.

SUMMARY

The UWCD has shown a willingness to meet the water needs of their citizens. The willingness is demonstrated in specific projects which are currently in operation, continued implementation of additional projects, and continued planning for future development of the water resources of the area. Their willingness to work with local water users has increased the water supply by many thousands of acre-feet. The local economy is much stronger as a result of these efforts. The result of the improved water supply has given the District the confidence to continue to work at meeting the ongoing need for additional water supplies to meet the growing demands. It is not an easy or simple task of meeting the water needs of today let alone the future needs. However, the past success of the District encourages the Board of Trustees of the District to continue to plan to meet the increasing water needs of the area. Future generations will reap the benefits of the dedicated and visionary looking water leaders of the Uintah Basin.

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IRRIGATION DISTRICT OPERATIONAL METRICS

Steven R. Knell, P.E.[1]

ABSTRACT

Oakdale Irrigation District (OID), located in the upper portion of the San Joaquin Valley, provides irrigation and domestic water service to rural northeastern Stanislaus County. The OID's service area is comprised of 72,345 acres of which approximately 55,000 acres are irrigated farmland. Within that service area are 40 miles of main canals inclusive of 23 hard and soft rock tunnels, 330 miles of laterals and pipelines, 110 miles of drains, 22 deep wells and 43 reclamation pump systems. Within the irrigated portion of the service area OID's agricultural customers grow a variety of crops, inclusive of pasture, almonds, walnuts, corn and rice. OID is also part owner of the Tri Dam Project with its sister district South San Joaquin Irrigation District. Tri Dam consists of three dam structures and four hydro-electric generating plants on the Stanislaus River.

The district had for many decades been a hand-to-mouth district until recently, where through some fortunate economic events; retirement of long term debt in 2002 and a renegotiated wholesale power contract in 2004, has acquired the financial means to begin replacing and modernizing its aged infrastructure. Prior to those events the district had been evaluating its performances in all aspects of daily operations to find ways to improve its operational efficiency and get the most out of its resources.

To reach that goal, early in 2002 the district set up some operation metrics to gage their performance. These metrics allowed the district to find areas of potential improvement and to measure change as change was implemented. This paper will discuss some of the operational metrics used, some quite simple, and how those metrics were used to bring change to OID.

METRIC 1 — CAPITAL IMPROVEMENT BUDGETS

Capital Replacement versus Capital Improvement

Irrigation districts often refer to their Capital Improvement Budgets (CIP) in the generic sense as it relates to their construction budget. District Managers should not lose sight of the two tiered aspects of a CIP budget; (1) to replace, rebuild and rehabilitate existing infrastructure to maintain system reliability; and (2) to build new infrastructure to meet modernization requirements brought on by changes in customer service demands or regulatory requirements to better manage its water resources. Both are essential elements in keeping our water systems functioning properly and at an acceptable level of serviceability and delivery efficiency.

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Balance in both elements is important and will largely be dictated by the availability of capital funding. Between the two categories of a CIP budget; CIP funds to replace old infrastructure or CIP funds to build new infrastructure, preference should dictate that replacement needs should have priority over the latter. It makes little economic sense to put old earth lined canals in pipelines when you have existing pipelines in your district leaking from age and deterioration.

In order to insure balance in a CIP program an irrigation district needs to understand what their system's lifecycle replacement needs are for its existing infrastructure. A lifecycle replacement analysis is a simple process, assuming one has an existing infrastructure/facilities inventory. The analysis will help determine if your CIP program is focused on its most important areas. If your organization lacks a facilities inventory of its system, it is suggested that one be done. Assigning a couple of employees to spend the winter offseason systematically counting the parts and pieces of your water and drainage systems is a worthwhile and essential expenditure of time. Once this data is known, it can be assembled into a simple spreadsheet; facility lifecycles assigned; annual replacement costs and project costs applied. The outcome will be a "replacement" budget for your existing system.

OID Example

In preparation of its 2004 budget OID took an existing facilities inventory and applied the methodology discussed above. The results are shown in Table 1. The exercise showed that OID had an annual lifecycle replacement budget requirement of about $4 million. OID looked back to its 2002 and 2003 budgets and noted the following;

1. Both the 2002 and 2003 CIP budgets were in the $2 million dollar range. An eye opening realization that showed that replacement needs were sorely underfunded by 100%.
2. Both the 2002 and 2003 CIP budgets showed CIP spending for "new" facilities to be 60% of the budget and funding for "replacement" facilities at 40% of the budget. Again, not too surprising, but a dangerous trend if continued.

Change in Focus

The importance of this exercise for district managers has multiple benefits. One is to educate the Board and the public on the replacement needs of your existing irrigation and drainage systems. There is no greater need for your CIP budget dollars than to invest in replacing your existing infrastructure before it meets its lifecycle term. Not recognizing that need; not addressing that need; and not getting a handle on meeting that need could put your district in a reactionary replacement mode. Replacements of facilities under failure mode will add 30-40% to the end cost. Not an efficient expenditure of constituent monies.

For OID, finding out it needed to be spending $4 million instead of $2 million a year was an eye opening exercise which brought to the forefront numerous questions, none of which had good answers. Like, how can we fund such an increase in expenses? How

Table 1. Estimated 2004 Capital Replacement Budget Needs

Asset Type	No.	Units	Life Cycle (years)	Replacement Needs (Annual)	Cost per Unit (Est.)	Budget
Shotcrete Canals	90	miles	45	2.0	$475,200	$950,400
Pipelines	100	miles	50	2.0	$450,000	$900,000
Pressure Boxes	481	each	60	8.0	$20,000	$160,333
Flumes	8	each	60	0.1	$100,000	$13,333
Turnouts	2,504	each	60	41.7	$5,000	$208,667
Turnout Gates	2,504	each	20	125.2	$1,500	$187,800
District Fence Gates	136	each	50	2.7	$1,000	$2,720
Culverts	623	each	60	10.4	$15,000	$155,750
Lateral Weir Headings	481	each	60	8.0	$45,000	$360,750
Drain Inlet Structures	322	each	60	5.4	$7,000	$37,567
Pumps	75	each	60	1.3	$150,000	$187,500
Access Reclamation	480	miles	50	9.6	$80,000	$768,000
Bridges	143	each	50	2.9	$35,000	$100,100
Annual Budget Requirement						$4,032,920

much can OID afford to do in-house (force account) and how much needs to be contracted out? Analysis showed that OID construction crews could do about $1 million of construction a year. More than that meant outside contractors would be needed. That fact raised subsequent issues; one being, OID did not have the in-house staff necessary to design, manage, inspect and control more than $1 million in outside contracts. That revelation raised further questions about adding staff to do the job which brought back budgeting and financing issues.

The end result was an investment in a Master Water Resources Plan that tied water conservation to water transfers to generate revenues to rebuild and modernize an old irrigation/drainage system with minimal economic impact to its current water customers.

METRIC 2 — WORKER'S COMPENSATION

Worker Safety in the Workplace

There is great value in a proactive safety program, both to the workers it protects and to the bottom line of an irrigation district. Safety is one of those things that can be easily taken for granted and it shouldn't be. However, after a number of years of multiple employee injuries (fortunately, none too serious) and significant lost work time from injured workers, it became evident that OID's safety program was broken and needed fixing. To begin that process OID did three things; (1) it called OSHA Consultation Service and requested onsite inspections, training and a written safety program review. This action gave OID short term protection from compliance protections against citations; (2) it contacted its Workers Comp provider and asked for help in restructuring its safety program; (3) it appointed a skilled and committed in-house employee to work full time with both OSHA and its Workers Comp provider to insure improvements and that change happened.

Reasons for and Cost of Poor Safety Practices

The reasons for such repetitive injuries were outlined by OID's Worker Comp Insurance providers at a management meeting held at OID's request in late 2003. Simply put, worker injuries result from a number of factors, inclusive of the following;

1. A poor safety program.
2. Employees who didn't care or practice safe work practices.
3. Poor supervision, in that safe work practices are not enforced by those with the job responsibilities to do so.
4. Poor management.

Safety and the practice of safety by employees is a workplace culture and workplace culture can take years to change, but the process needs to start in order to get there.

The Experience Modification (E-Mod) Ratio as used by Workers Comp Insurance providers is a measure of the workings of the district's safety programs. In the 2003-04 calendar year OID had an E-Mod of 1.48. OSHA states that any employer with an E-Mod over 1.25 is a "high hazard employer" and subject to additional scrutiny by OSHA, which is not a good thing.

The economics of a high E-Mod Ratio is simple to understand. The portion of the E-Mod over 1.0 is the percentage an organization pays above the average rate of those in their same insurance pool. For OID, with its E-Mod Ratio at 1.48, it meant OID was paying 48% more than the average organization in its same insurance pool. In dollars, OID paid $378,424 in 2004 for Workers Comp coverage.

The Pay Back

Today OID has an E-Mod of 0.91 with a goal of getting to 0.60. It has taken OID nearly 4 years of incremental change but the return has been impressive. In 2008, OID's Worker Comp Insurance premiums were $160,836, a savings of nearly $218,000 a year from its 2004 rate. While these are direct cost savings, the indirect cost savings for such a program change are easily multiples of this number. Savings in overtime pay, improvement in worker productivity and moral, reduced administrative time for tracking and management can easily triple this savings.

Philosophical Business Change

To instill this change OID adopted a new philosophical approach to safety. Wherein the past OID expected injuries as part of their work culture, now a “target zero” approach prevailed to any and all injuries. Changed too was the responsibility of making safety someone else’s job to making it a team effort. The Team does well, the employees do well incentives were established. The Target Zero philosophy has been articulated from the Board of Directors to the end of the organization chart and back. OID’s Board commitment is shown through their support of safety BBQ’s, safety incentive pay, purchase of modern equipment, etc. all geared to providing a safer work environment.

The OID Board, Management and Staff all take pride in their safety accomplishments. The implemented safety programs, the change in safety culture, the proactive response to addressing hazards in the workplace and a Safety Counsel made up of employees dedicated to worker safety were all contributing factors to this effort.

METRIC 3 — HEAVY EQUIPMENT UTILIZATION

Setting the Utilization Parameters

Equipment management and its utilization in the workplace can be a large cost item in an irrigation district’s budget. With knowledge of your workforce and equipment capabilities, simple metrics can be put together that can improve equipment utilization through better planning and scheduling. The key is in setting the bar from which to measure these parameters.

The total time available to operate heavy equipment is a simple function of the number of operators within your organization. Most managers know that there are 2,080 hours in a work year for hourly paid employees. Hourly employees generally get a 30-minute unpaid lunch, which does not count against the 8-hour work day, and two 15-minute breaks that do count against the 8-hour day. Assuming 45 minutes lost to the morning line-up, driving to the job site, equipment check and warm-up and safety walk around, and another 45 minutes at the end of the day to the drive back to the yard in the afternoon and filling out the time card, the productive 8 hour work day is down to a potential of 6-hours of productive equipment time (restroom breaks are included in these times). That’s a 25% inherent efficiency loss for a workday.

Caterpillar, in their Performance Handbooks, rates their equipment productivity based on a 52 minute hour of operator output on a machine. That is 15% inefficiency and likely includes the work day starting when the operator gets to the job site, as is typical for union laborers. With that said, the best one could expect on equipment utilization is around 75-85%.

Measuring Performance

Performance measurement is simple. Each piece of heavy equipment has an hour meter on the engine. For the meter to register the engine needs to run above the idle speed. At the end of a year period (preferred period of measurement), the organization totals up the number of equipment hours on all heavy equipment and compares that to the number of hours of operator time made available during the same year.

OID Example

OID did this in 2002 to get a handle on its equipment utilization. At the time OID had 6 full time operators generating an available work hour pool of 12,480 hours (6 workers X 2,080 hours/work year). At the end of 2002 OID's equipment utilization for all equipment operated by its heavy equipment operators totaled 4,266 hours. With those numbers the utilization rate for OID's heavy equipment was 34% (4,266/12,480). If 75% utilization was the best one could expect, the 34% represented a significant deficiency.

Upon evaluation, the two culprits in the low utilization numbers were unexpressed expectations of performance to employees and poor scheduling by supervisors. Both these parameters were addressed in the subsequent two years and the results and progress are shown in Table 2.

Once employees found out management cared about equipment hours and were looking at hours as a measure of performance, performance improved. Once supervisors realized that coordinating the scheduling of jobs by areas as opposed to date received helped tremendously in reducing the travel time of equipment from job to job, resulting in more operating hours for the equipment. Once both these groups realized that if they coordinated better amongst themselves, both could show betterment.

Equipment Production

All heavy equipment has been rated for productivity by their manufacturer. Productivity units are generally expressed in cubic yards per hour. Measuring equipment (i.e. operator) productivity is an intermittent management process necessary to insure both equipment and operators are being productive.

Ditch cleaning using an excavator or backhoe to pull out sediment and stack it on the adjacent canal or drain banks is a very common irrigation district maintenance operation. Where good lengths of the system are scheduled for cleaning, tracking equipment move-in and move-out dates, length of excavation and spoil generated are all measurable units to arrive at cubic yards produced over time (cubic yards per hour). Comparing that

Table 2. Heavy Equipment Usage Improvements 2002-2004

Equip #	Year	Description	Purchase Date	OID Age (Yrs)	Begin (Hrs)	Hours 1/1/02	Hours 1/1/03	Hours 1/1/04	Hours 1/1/05	Avg. Use Pre-2002	Use 2002	Use 2003	Use 2004
873	2000	Skid Steer Loader	May-00	5.1	15	254	389	541	650	121	135	152	109
331X	1999	Mini- Excavator	Oct-99	5.7	4	988	1390	1792	2057	366	402	402	265
C 12G	1986	Motor Grader	Nov-86	18.7	3	4694	5067	5754	6239	299	373	687	485
C 215	1986	Excavator	Oct-86	18.8	4	8239	8959	9865	Sold	521	720	906	Sold
SK 250	2001	Excavator	Jun-01	4.0	5	500	1354	2036	2535	500	854	682	499
C420D	2001	Loader- Backhoe	Jun-01	4.0	2	403	1152	1750	2197	403	749	598	447
C 426	1985	Loader- Backhoe	Jul-86	19.1	3	6506	6797	6941	Sold	404	291	144	Sold
C 613B	1979	Self-Load Scraper	Feb-96	8.3	Mtr. Chg.	1112	1163	1501	1666	210	51	338	165
C 920	1979	Loader	Jan-79	26.5	2	1853	1962	2053	2086	79	109	91	33
C 950B	1986	Loader	Nov-86	18.7	3	4201	4673	4850	5176	268	472	177	326
C D5B	1984	Dozer- Rippers	Mar-84	24.3	3	5750	5928	Sold	0	270	178	Sold	0
C D5H	1986	Dozer-Winch	Nov-86	18.7	2	5211	5492	5810	5963	332	281	318	153
C D6H	1986	Dozer- Rippers	Dec-97	7.6	1,191	2220	2679	2997	3518	483	459	318	521

	Pre-2002	2002	2003	2004
OID Equipment Hours	4,255	5,074	4,813	3,003
Rental Equipment Hours	0	0	1,417	3,833
Total Annual Hours of Usage	4,255	5,074	6,230	6,836
Percent Increase in Equip Utilization		19%	46%	60%

calculated number to the equipment productivity rates in the owner's manual will determine if one is getting the most out of the machine and the operator.

After a month or so, and the spoil dries down, the follow-up operation is to bring a dozer in to knock down the spoil and reconstruct the road by back-dragging. From the canal/drain cleaning operation done by the excavator, the cubic yards sitting on the ditch bank are known; hence the same review of dozer productivity can be repeated.

METRIC 4 —MEASURING MATERIAL CONSUMPTION

Measuring Material Consumption

OID has a stores warehouse (Stores) whereby consumable goods such as, cement, nails, lumber, nuts and bolts, pipe, gates, etc. are inventoried in and out of stock for work to be done at the district. At OID work crews receive "job set-up forms" detailing their work assignment(s) for the day(s); they check out that material necessary for the job from Stores; and do the job.

It is that consumable inventory which moves into and out of the Stores that is a metric indicator of work done. It is also a measure of the productivity of work crews, supervisor scheduling abilities and even morale. For OID this change has been dramatic. Table 3 shows the change in Stores inventory over recent time.

Table 3. Inventory Through and In Stores Warehouse

Year	Inventory Through Stores	Inventory In Stores (yr. end)
1999	$85,434	$59,678
2000	$67,097	$64,541
2001	$70,828	$70,697
2002	$119,098	$96,991
2003	$153,332	$120,345
2004	$104,824	$121,501
2005	$354,790	$398,088
2006	$993,535	$407,328
2007	$196,050	$271,414
2008	$234,563	$272,258

Throughout the period 1999-2008 the number of personnel assigned to do work has remained relatively unchanged. OID maintains a year-round 10-person workforce for construction and maintenance work. After water season OID moves all 23 Distribution System Operators (ditchtenders) to the Construction and Maintenance Section (C&M) for winter assignment. On a weighted basis, the available workforce to do C&M activities on an annual basis is about 20 workers.

Analyzing the Change

Table 3 illustrates the changes in Stores inventory beginning in 2002 and continuing through 2008. The substantial changes in 2005 and 2006 were due to two factors. Pipe replacement projects driven by failing infrastructure being one factor and a pipe shortage brought on by Hurricane Katrina being the other. This combination of events drove OID to stockpile pipe in its Stores for later use. However, 2007 and 2008 are indicative of a current leveling off of consumed inventory.

Consumed inventory goes to two areas, construction projects and maintenance projects. Generally construction projects have a higher materials/transportation cost to labor cost for a given job. Maintenance work is generally the opposite, little cost towards materials/transportation and high labor costs. OID's next metric will be in determining and arriving at the unit cost of projects, both construction and maintenance, to further look for advantages.

SUMMARY

This paper discussed some of the operational metrics established at OID to measure both the efficiency and productivity of work. As can be seen by some of the examples; not all changes to improve work output results in lower costs. Higher equipment utilization increases fuel consumption. Higher worker productivity increases both materials consumption and transportation costs, and some of these costs can be substantial.

Change at OID is attributable to numerous factors; a change in management and management expectations; placement of key personnel in charge of day-to-day activities who know how to schedule jobs, equipment, and labor to get work done; supervisors who challenge their employees and most importantly, employees who stepped up to the challenge, address these changes and become partners in advancing the needs of an irrigation district.

Whether you are a district with money or not; the establishment of business metrics is important. Organizations, regardless of financial position, should be managed to attain the highest productivity and utilization of their available assets, whether they be financial assets, equipment, labor or resource assets. Irrigation district management needs to develop forward thinking strategies to meet the challenges and changes of our business if sustainability is the goal for our organizations.

SUSTAINABLE URBAN DEVELOPMENT: AN IRRIGATION DISTRICT'S EVOLVING ROLE — FRESNO IRRIGATION DISTRICT

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ABSTRACT

At almost a century old, the Fresno Irrigation District (FID) is evolving from a purveyor of agriculture water to an agency supporting sustainable urban development. This critical shift is needed in order to secure water supplies for the future. For years, FID has been faced with a groundwater basin in a state of overdraft. This condition has focused FID efforts to decrease municipalities' reliance on groundwater through better utilization of the FID's surface water supply. Their work with other agencies has successfully decreased a reliance on groundwater by maximizing the use of various water sources. By using a combination of snow melt water from California's Sierra Nevada Mountains, water from urban storm water retention basins and reclaimed water from the municipal wastewater, FID has reduced the dependence on groundwater, thereby ensuring a sustainable water supply for eastern Fresno County and its future growth.

INTRODUCTION

At the time of the FID's formation in 1920, the two communities currently within its boundary, the city of Fresno and the city of Clovis, were small farming towns. They occupied a few square miles and were surrounded by prime farmland in California's arid Central Valley.

In 1920, Fresno County had approximately 128,000 residents. Today, residents of Fresno County number nearly 900,000, with a majority residing in the Fresno-Clovis metropolitan area. According to the 2000 U.S. Census[3], the city of Fresno encompasses 104 square miles and the city of Clovis encompasses 23 square miles. Without considering the 2001 to 2007 housing boom, urban development made up at least 130 square miles of FID's 383 square mile service area, or 34%. At the time of this report, there are no significant plans to decrease or control urban growth rates in the area. The conversion of rural, undeveloped or agricultural lands, which have a low runoff and increased potential for groundwater recharging, to higher density urban communities has resulted in significant challenges to FID water supplies and water management.

Facing population and urban area growth of this magnitude, combined with the area's heavy reliance on groundwater pumping, FID recognized that changes in local water management would need to be explored and incorporated into their operations.

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[3] United States Census Bureau, *Census 2000*, http://www.census.gov/main/www/cen2000.html (April 2009).

FID is now faced with two additional conditions that are decreasing available surface water supplies. Concerns over climate change and the contentious legal issues surrounding water rights have also affected how, when and in what quantities, water can be made available to FID. The Department of Water Resources is reporting the third consecutive dry year in the Central Valley[4]. Lower than average annual snow pack levels in the Sierra Nevada Mountains are a concern, particularly if the trend proves to be a product of long-term climate change. Below normal runoff coupled with recent litigation requiring increased flows into the San Joaquin River for wildlife restoration have resulted in reduced water available for agriculture and urban applications, including recharge, throughout FID's service area.

FID has developed and promoted sustainable practices amongst its staff and water users as well as with local public agency counterparts. They continue to work closely with the cities of Fresno and Clovis, as well as the Fresno Metropolitan Flood Control District (FMFCD), to develop sustainable practices for the benefit of the urban and agricultural end user. These practices include: developing, or assisting in the development of, detention and retention basins that utilize storm water runoff and winter snow melt for groundwater recharge; providing conveyance of surface water from the Kings River and San Joaquin River to multiple surface water treatment plants in the major metropolitan area; and beneficially reusing reclaimed water from various wastewater treatment facilities located within FID's boundary.

BACKGROUND

In 1920, FID purchased the Fresno Canal and Land Company holdings, including extensive water rights from the Kings River. The newly-formed public FID acquired 250,000 acres and 600 miles of canals and vast distribution works that were constructed between 1850 and 1880[5]. In the last 90 years, FID has expanded to own and operate over 800 miles of canal and pipeline throughout Fresno County. Currently there are more than 4,700 landowner turnouts throughout FID.

The construction of Pine Flat Reservoir for a flood control and water conservation unit was completed in 1954 by the Army Corps of Engineers. Pine Flat Reservoir has a storage capacity of one million acre-feet capacity. The FID has entitlement to approximately 26% of the average runoff of the Kings River that feeds this reservoir. This is approximately 12% of Pine Flat Reservoir's one million acre-feet capacity. The FID is the largest of all 28 agencies allocated waters from Pine Flat Reservoir.

DELIVERING WATER FOR POTABLE WATER USE

FID works closely with the cities of Fresno and Clovis. FID and the city of Fresno have contracts with the Friant Division of the Central Valley Project to purchase up to 135,000

[4] California Department of Water Resources, *California's Drought Year 3* http://www.water.ca.gov/drought (February 2009).
[5] Fresno Irrigation District, *Welcome to the Fresno Irrigation District* http://www.fresnoirrigation.com/history.html (2003).

acre feet annually of San Joaquin River waters to be used for recharge in and around Fresno[6]. In addition, 60,000 acre feet are allocated annually to the city of Fresno, and when it's available, they purchase an additional 75,000 acre feet. This water is diverted throughout the FID's system of water recharge and banking facilities.

Within the last five years, both municipalities have constructed surface water treatment plants that rely on FID water via the Enterprise Canal (Canal). This new use of FID resources has impacted FID operations most notably in the areas of monitoring and water quality.

Monitoring

Increased efforts to monitor the timing and flow of water throughout the system are necessary to ensure the delivery of water for domestic use. FID elected to update and expand their system of telemetry, automation and control structures. Water levels are now more easily and accurately monitored and controlled, helping to deliver a consistent, efficient amount of water to the municipal treatment plants. Because the Canal also takes on seasonal stormwater, new pumping facilities also had to be installed to help mitigate the effects of large or unanticipated rainfall. Other improvements included the widening and deepening of the Canal in some areas to provide additional capacity.

FID and the two municipalities have an annual delivery schedule that allows for an eleven month continuous delivery period. One month a year, typically in November, FID stops delivery to perform maintenance and other related construction activities. During this time, the surface water treatment facilities also cease operation and perform maintenance. If construction activities require additional time, bypass strategies and infrastructure have been put in place to deliver water to the plants.

Quality Management

Protecting the water quality before it reaches the cities' treatment plants is now vitally important. For many years, the Canal transported water from the Kings River to agricultural lands in northeast Fresno County. As the earthen-lined channel followed the contours of the eastern Sierra Nevada Foothills, the canal received uncontrolled stormwater run-off, mostly from neighboring pastures and rural stream channels.

The historic drainage patterns of Canal-adjacent pastures and farms have drained run-off into the Canal during storm events. If cattle, other animals or pesticides are near the Canal, bacteria and other contaminants can be introduced to the water. In order to prevent these contaminants from getting into the Canal, FID changed drainage patterns to route storm run-off into other areas where it could not influence the Canal. The Canal was also fenced off in some areas to prevent cattle, other animals, and unauthorized individuals from having access.

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[6] Friant Water Users Authority, *About the Friant Division,* (unknown date).

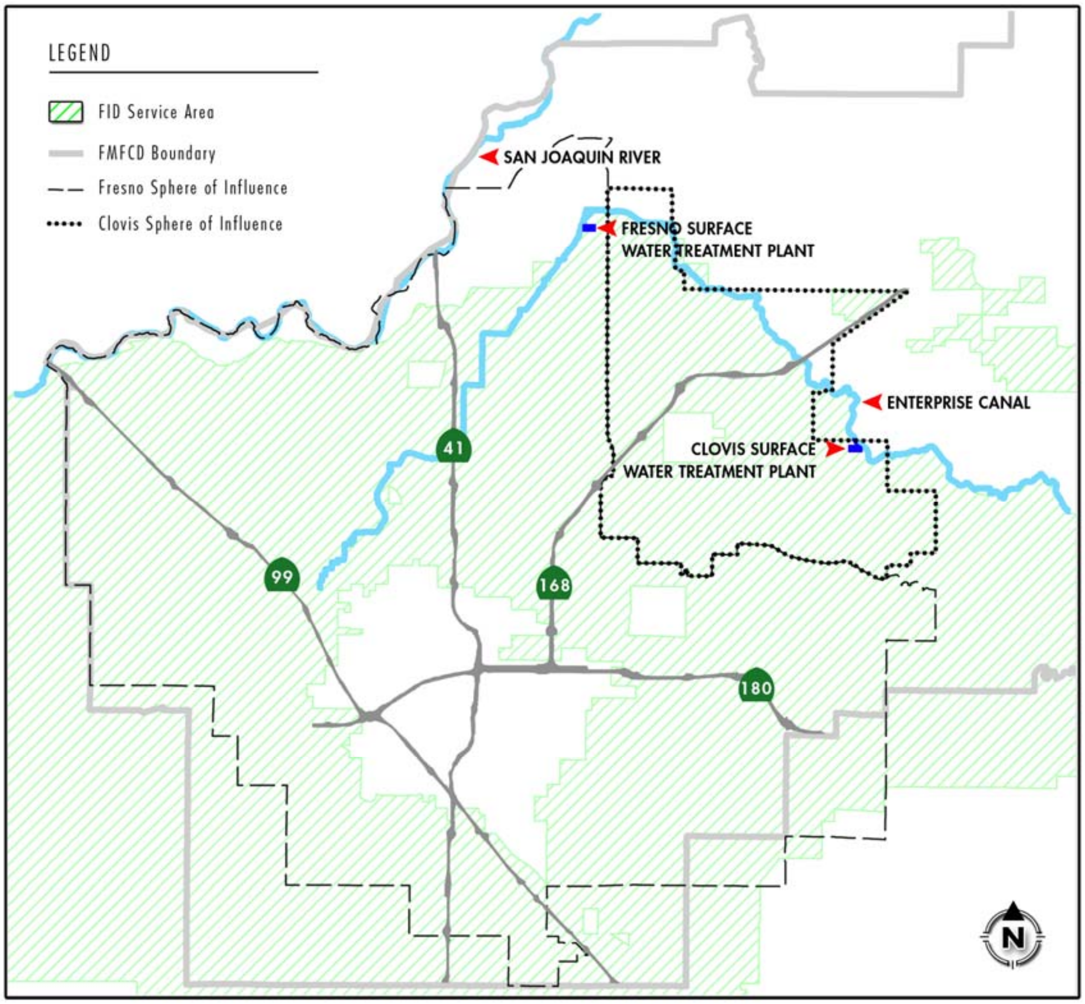

Figure 1. Sources of potable water from FID facilities

There are many more regulations imposed on the Canal water now that it is used for potable water. As a result of these regulations, FID has to make improvements to the Canal, perform additional maintenance, and prevent illegal discharges in order to preserve water quality. It also has to work with local agencies, including the California Department of Public Health (CDPH), to inform and educate people about the Canal's use.

In addition, many agencies now have a stake in the Canal's water quality. FID must work with other local agencies including the cities of Fresno and Clovis, CDPH, the Fresno County Sheriff's Department, and the California Highway Patrol. These agencies meet quarterly to discuss issues such as points of access, illegal discharges and discharge prevention, public education, as well as coordination and operations.

Canal access roads had to be improved so that they were vehicle-accessible year round. The cities of Fresno and Clovis provide daily patrols along the Canal searching for illegal discharges and potential contaminating activities. New protocols for reporting contaminating activity had to be developed and tested, including emergency treatment plant shut down to prevent unsafe water from entering the domestic water system. FID also patrols the Canal periodically by vehicle and helicopter.

In an effort to prevent illegal discharges, FID engaged in an education campaign to inform all of the adjacent land owners of the Canal's role in providing drinking water to the metropolitan area. This is a continual process in which the cities, Sheriff's Department and California Highway Patrol also contribute.

STORM WATER MANAGEMENT IN THE FRESNO-CLOVIS METROPOLITAN AREA

In 1958, the Fresno Metropolitan Flood Control District (FMFCD) was created to serve the flood control needs of nearly 400 square miles of eastern Fresno County. From the beginning, FID has worked closely with Fresno Metropolitan Flood Control District to divert waters stored in detention basins throughout its service area, to agricultural end users and various recharge facilities operated by FID.

Storm water management in the Fresno-Clovis metropolitan area is complicated by the flat gradient of the area and the lack of natural streams or lakes to receive the runoff. The local agency with primary responsibility for storm water management is the FMFCD. The FMFCD has developed a storm drainage management concept that involves the division of the community into local watersheds, called drainage areas, ranging in size from 200 acres to 600 acres. Each drainage area has a planned collection system and a retention basin. Within the FMFCD's 400 square-mile service area, there are 152 retention basins. The collection system is sized to provide a two-year recurrence interval level of service. The retention basins are sized to retain the runoff from the drainage area resulting from six inches of rainfall in the area.

The retention basins process storm water by percolating the runoff into the groundwater table, thereby providing for the conservation of the runoff and recharging the groundwater supply. However, many basins have percolation rates that do not exceed 0.1 inches per day. Prolonged periods of rainfall that produce runoff volumes that exceed the available storage volume and processing capabilities of the basins occur in the Fresno-Clovis metropolitan area in seven to 10 year intervals. For that reason, FMFCD has equipped many of the basins with de-watering pumps with 5 to 10 cubic feet per second (cfs) discharge capability. The estimated total discharge capability of these pumps is 570 cfs. The discharge point for all of these pumps is into FID's canal and pipeline distribution system.

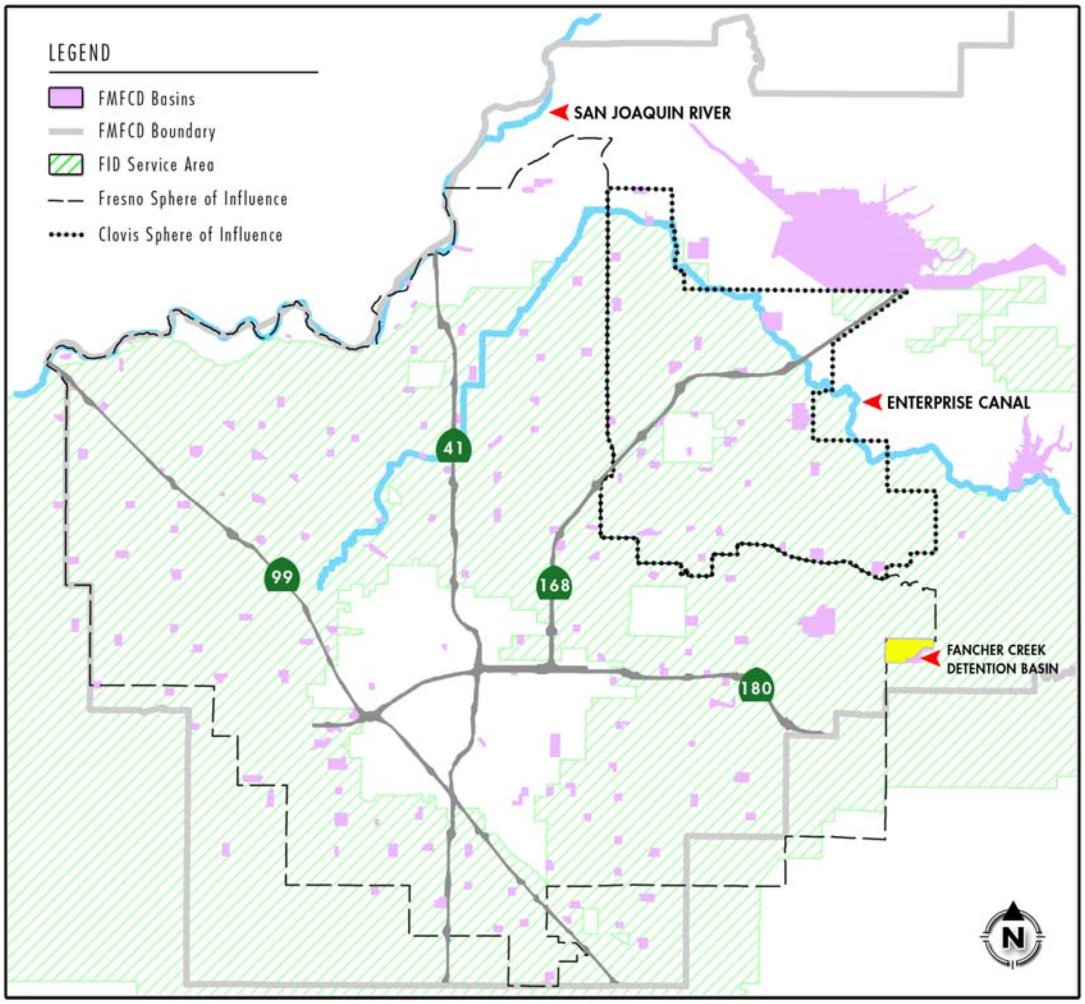

Figure 2. Storm water retention basins

The Fresno-Clovis metropolitan area must not only deal with runoff generated within the metropolitan area, but it must also deal with storm water flows within streams that originate in the western foothills of the Sierra Nevada and whose remnant channels traverse through the metropolitan area. These streams include the Big Dry Creek, the Alluvial Drain, Pup Creek, Dog Creek, Redbank Creek, and Fancher Creek. Before the metropolitan area developed, these streams discharged into alluvial fans west of what is now the metropolitan area. When irrigation was brought to the area, most of these channels were cooped and improved for use as canals. The two major canal systems that convey storm water through the metropolitan area are the Mill Ditch/Herndon Canal and the Fancher Creek/Dry Creek Canal. Between 1994 and 1999, FMFCD and the US Army Corps of Engineers constructed dams and detention basins on these creeks to reduce the peak discharges through the metropolitan area for events up to the 200-Year recurrence interval. The peak discharge rates were reduced from thousands of cfs to 90 cfs in the Big Dry Creek, from 600 cfs from Redbank Creek to a 200 cfs spill into the Mill Ditch/Herndon Canal system, from 4000 cfs to 200 cfs in Dog Creek, from 300 cfs to 23 cfs in Pup Creek, from 340 cfs to 24 cfs in Alluvial Drain, and from 1400 cfs to 80 cfs in Fancher Creek. The net result is that foothill peak discharges through the metropolitan area were reduced to 380 cfs with 300 cfs being allocated to the Mill Ditch/Herndon Canal system and 80 cfs allocated to the Fancher Creek/Dry Creek Canal system.

The disposal of foothill stream flow and urban flood water is managed through the cooperative efforts of FMFCD and FID. The FID irrigation canal and pipeline system provides the only means for transporting large discharge rates through and out of the metropolitan area. The disposal occurs through two FID canals that have a combined peak discharge capacity of 700 cfs. The Mill Ditch and Herndon Canal system, which conveys foothill and urban storm water, has a calculated bank full capacity of 500 cfs at this time. This canal system runs westerly and northwesterly through the middle of the metropolitan area and disposes into the San Joaquin River. The Big Dry Creek Canal has a capacity of 200 cfs and disposes into a floodwater retention basin located in the southwest corner of the FMFCD boundary. The basin is surrounded by three square miles of land for which flooding rights have been acquired.

Rainfall patterns that have the potential to create large scale flooding within the metropolitan area are prolonged general rain storms that produce significant runoff rates and volumes, as opposed to the thunderstorm systems that create significant runoff rates, but not volumes. The general rainfall storm produces runoff both in the foothill areas, which charge the foothill streams, and within the metropolitan area at the same time, which can overrun the retention capacity of the basins. A coincidence of the peak discharge rates from the foothill streams passing through the metropolitan area at the same time that the retention basins are full or near full produces a significant storm water management problem for FMFCD and FID. The Mill Ditch/Herndon Canal system poses the largest management problem due to a foothill peak flow allocation of 300 cfs and a potential urban basin relief pumping rate of 300 to 350 cfs when compared to a canal capacity of 500 cfs. The Dry Creek Canal system, with a capacity of 200 cfs can provide some relief to the Mill Ditch/Herndon Canal, but it has an urban pumping potential of up to 200 cfs and a foothill allocation of 80 cfs.

The rainy season in the Fresno area is from October 1 to April 30 with most of the significant rainfall occurring in the months of December, January, February, and March. The irrigation season usually begins on April 1, but the FID begins charging the canals between mid-February and mid-March. In addition, there are some canals that carry water all season to provide for fish habitat enhancement and deliveries to the city of Clovis and city of Fresno surface water treatment plants. The perfect storm, from a storm water management horizon, is when a wet winter is followed by a prolonged rainfall pattern that occurs during mid-March when the canal system is charged for deliveries and then, relatively quickly, the capacity in canal system must be made available for moving storm water through and out of the metropolitan area.

Fortunately, the prediction capabilities of the National Weather Service have improved over the years and FMFCD and FID staff have worked very hard to learn how to coordinate their efforts to manage the storm water and irrigation water at the same time. A key component in the ability to manage the storm water and irrigation water is the capability to quickly dewater the charged canals. This problem became easier to solve since the completion of the Fancher Creek Detention Basin (FCDB). The FCDB provides detention of flows in the Fresno Canal/Fancher Creek channel east of the metropolitan area. The Fresno Canal carries combined FID irrigation water and Fancher Creek storm water and is a major upstream tributary to the Mill Ditch/Herndon Canal system. The FCDB has the capability to close off all outflows from the basin, except 80 cfs to Fancher Creek, thus creating up to 300 cfs of capacity in the Mill Ditch/Herndon Canal downstream of the basin in a very short period of time[7].

The FCDB has 2,180 acre feet of storage at the basin design high water elevation that can be accessed as quickly as the control gates can be closed. The flow out of the basin into Mill Ditch is controlled by a headworks structure with three automated overshot and two automated undershot gates. Telemetry status of the basin water surface elevation and the gate positions is provided to the operations centers of FID and FMFCD and the gates can be controlled from the FID Operations Center.

The FCDB was originally conceived by the US Army Corps of Engineers as a part of the master flood control plan for the Fresno metropolitan area. Subsequent cost – benefit analysis determined that the basin had a cost benefit ratio of less than 1. The lands protected by the basin were mostly agricultural at the time the analysis was performed. Subsequent development within the southeast metropolitan area has increased the amount of flood damages that could occur in a significant storm. For this reason, FMFCD chose to construct the basin as a locally-funded project rather than attempt to qualify the project for federal funding. The design of the basin took five years to complete. The major flow control components of the basin, the headworks, the dam, the spillway, and control weirs were constructed within or adjacent to the Fresno Canal, which is an active irrigation channel. That limited the construction time to winter months when the canal was dry. It took over three years to complete the construction of these components due to this limitation. In addition, the dam creating the detention basin is under the jurisdiction of the California Department of Water Resources Division of Safety of Dams and this added significant review time to the project design.

One of the key components considered in the design of the FCDB was to provide operational flexibility in the structures and gates so that they could be managed by FID during irrigation season to distribute irrigation water to the Mill Ditch and Fancher Creek. FID also uses the basin for buffering their system when downstream demand drops below upstream supply as well as for flood control operations when the basin is needed to detain storm water flows. These operational issues were resolved through the close cooperation of the two agencies during the design effort, the extensive use of telemetry and the provision for the implementation of a Supervisory Control and Data Acquisition system. This capability will allow for real time knowledge of channel capacities and the ability to change control gate opens to utilize channel capacity and basin capacity and allow both agencies to work more seamlessly in the management of storm water within the metropolitan area.

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[7] Cordie R. Qualle, PE, et.al. "*Fancher Creek Detention Basin Design Report*" (Blair, Church & Flynn Consulting Engineers, 2005).

RECLAIMED WATER

Continued urbanization has created a need for expanded and new wastewater treatment plants. As discharge requirements to natural stream channels become more restrictive, municipalities look to the FID as a potential recipient of reclaimed water. FID has worked extensively with the city of Fresno and the city of Clovis to receive the reclaimed water. Receiving reclaimed water has proven to be challenging as discharges vary both in quality and quantity. In addition, increased regulatory requirements by the California Regional Water Quality Control Board (Regional Board) are becoming more stringent with the use of the recharged water once within the FID's distribution system.

Most recently, FID has entered into an agreement with the city of Clovis to receive approximately 8,000 acre feet annually of reclaimed water from their newly constructed wastewater treatment facility[8]. The treated water is disinfected tertiary in accordance with the State of California Title 22. Under state law the city of Clovis is required to recycle as much processed wastewater as possible in order to offset the city's overall water demand. The city plans to offset this demand by using reclaimed water for landscape irrigation within city road right-of-ways and parks. The infrastructure necessary for disposing of all reclaimed water within the city has yet to be constructed. For this reason, during the initial operation of the treatment facility, the city most likely will look to FID to receive the majority of the reclaimed water until the infrastructure is completed.

Once the city has had the opportunity to complete construction of a reclaimed water distribution system, the amount of water needed for landscape irrigation will vary seasonally. Because of low evapotranspiration rates in late fall and during the wintertime, FID will see the majority of the discharges from the treatment plant occurring during what would normally be considered their maintenance period. Historically, FID has ceased operations of channels once water was no longer available from Pine Flat Reservoir. On average, this usually occurs from the middle of October to the first of March. Historically, water control structures and conveyance facilities were manually adjusted for drain down and used for conveying storm water during the wintertime. In order to minimize costs to FID, staff normally used to perform water operations during the delivery season are placed on crews for performing maintenance and construction activities. An increased level of operations will take place during the winter months when the city's plant comes on-line.

Receiving reclaimed water during late fall and winter months when there is little flow from the river and/or storm drainage has proven to be problematic. The Regional Board requires a river/storm water to reclaimed water dilution ratio of 20 to 1 for groundwater recharge basins. This requirement has put a greater focus on operations to ensure that proper dilution ratios are met. As mentioned above, the majority of the reclaimed water delivery occurs when water is not being diverted from the Kings River and a majority of the land crops are dormant, leaving little option for disposal other than recharge basins.

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[8] Luis M. Gonzalez, PE, et.al. "Clovis Recycled Water Master Plan" (Blair, Church & Flynn Consulting Engineers, 2006).

The Regional Board allows the dilution to occur over an average annual basin volume rather than an instantaneous basin volume. This will allow FID to utilize existing groundwater recharge basins during the fall and winter months for the disposal of the reclaimed water, even though the concentrations within those basins will exceed 20 to 1 during those seasons. FID will have a greater need for tracking and tracing the reclaimed water, and points of discharge, to ensure that the annual allotments to the regulatory basins are not exceeded.

The District also receives approximately 30,000 acre feet per year of water from the Fresno/Clovis Regional Wastewater Reclamation Facility, operated by the city of Fresno.

Fresno’s treatment plant is a secondary treatment facility. Most of the treated effluent is delivered to percolation ponds on the city property. Some of the water is delivered to farmers for irrigating non-edible crops. Fresno is required by the Regional Board to have reclamation wells around the perimeter of the percolation ponds to monitor the groundwater in the immediate vicinity. These wells are drilled to various depths and the water is tested to provide data and evaluate what effect the ponds have on groundwater quality. Water is pumped out of the ground near the ponds also to help protect the groundwater quality. This water is pumped into either Dry Creek or the Houghton Canal. Although the water is pumped from the ground, the Regional Board still defines it as reclaimed water and must be treated as such due to its high nitrogen and total dissolved solids concentrations.

The city’s permit to discharge to the canal is nearly 20 years old and therefore has much less stringent requirements than that of the new Clovis Wastewater Treatment Plant discharge permit. For this reason blending and dilution ratios for recharge basins are not required by the Regional Board.

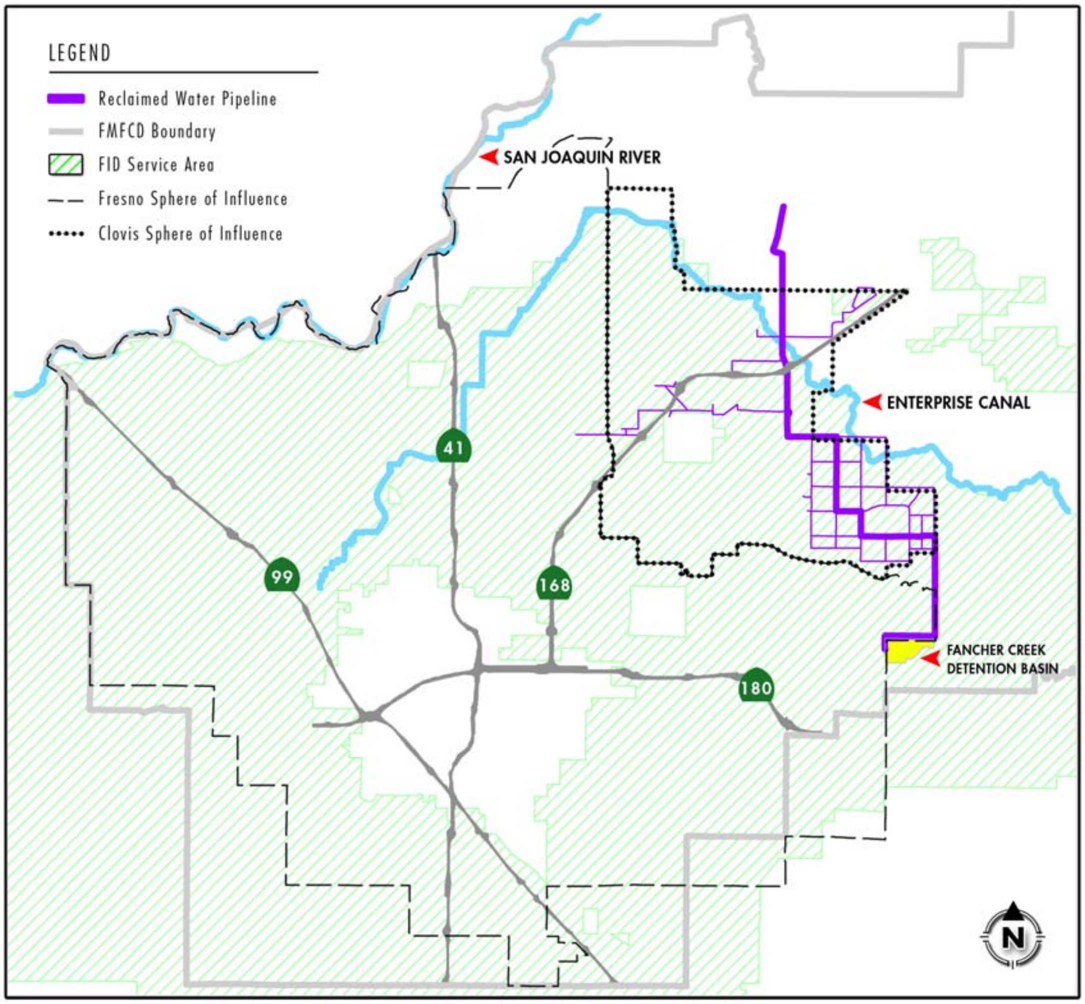

Figure 3. Recycled water infrastructure within FID

FID receives reclaimed water from Fresno's treatment facility eight months per year from April through November. The facility is located within the southern portion of the FID where few groundwater recharge basins are present. In order to find a reuse location for the water, FID has established a program in which growers may sign up to receive reclaimed water allocations and negotiated a recipient fee for the reclaimed water. The revenue received by the city of Fresno offsets operational and maintenance costs associated with receiving the reclaimed water.

Fresno's wells are problematic and not a reliable source of water for the farmers that have purchased allocations. The delivery is inconsistent and not guaranteed should the wells become inoperable. This causes more difficulty for FID when trying to provide water.

SUMMARY

Since the formation of the FID in 1920, the urban land use has increased from 20 square miles to 130 square miles. The cities of Fresno and Clovis make up nearly one-third of the FID's service area. In 1958, the Fresno Metropolitan Flood Control District was created to meet the flood control needs, including rural runoff and urban storm management, of nearly 400 square miles. Converting productive agricultural lands to high-density urban communities has resulted in significant impacts to the FID's water supplies and water management. These impacts include: depleted groundwater supply; a need for storm water conveyance and storage facilities; and most recently, the need for beneficially reusing treated domestic wastewater.

Historically, the cities of Fresno and Clovis depended solely on groundwater to meet their domestic water needs. Within the past five years, both communities have constructed surface water treatment facilities capable of treating 46,000 acre feet of surface water annually. FID is instrumental in isolating selective conveyance channels and ensuring clean reliable surface water delivery to both treatment plants.

Optimizing the use of storm water runoff has become a sustainable means of securing future water needs. Storm water runoff comes from eastern Fresno County's rural streams, which convey collected runoff towards the metropolitan area, and from 152 storm drainage detention basins within the urbanized areas of Fresno and Clovis. Retained storm water from these two sources is used for groundwater recharge, as well as supplemental water supply that can offset needed surface water deliveries. In addition, FID, with support from other agencies, has constructed new water banking facilities capable of recharging 10,000 acre feet annually[9].

The beneficial reuse of tertiary treated domestic wastewater is the FID's latest endeavor to ensure sustainability. Continued urbanization has created the need for new and expanded wastewater treatment plants. As discharge requirements to natural stream channels become more restrictive, municipalities look to FID as a potential recipient of reclaimed water. Accepting treated domestic wastewater for agricultural use has produced a new set of challenges.

FID readily acknowledges the importance of preserving water supplies for the future. Through its efforts to conserve, reuse and balance water sources, FID is leading the way in developing sustainable resources for the immediate and future benefit of the Fresno-Clovis metropolitan area.

[9] Ron McGrath, interview held during design meeting, Fresno, California, June 2008

IMPROVING NEVADA CITY'S WATER SUPPLY SYSTEM

W. Martin Roche[1]

ABSTRACT

The City of Nevada City, California (City) is taking steps to improve its domestic water supply, treatment, and distribution system. The City, with a population of approximately 3,000, is located in Nevada County in the foothills of Northern California, and has a rich history dating back to the gold rush era in the nineteenth century.

The City's water supply comes from two sources; natural runoff of Little Deer Creek under an appropriative water right, and raw water purchased from the Nevada Irrigation District (NID), whose service area completely surrounds the City. Water is stored in a 54 acre-foot reservoir and treated at a treatment plant with a design capacity of 2.0 million gallons per day (mgd). Over the past few years water use has averaged about 740 acre-feet per year, or 0.66 mgd. The average per-capita use is about 220 gallons per day (gpd), which is typical for use in California where significant conservation measures have not yet been implemented. Peak use has been less than 1.40 mgd, well within the treatment plant's design capacity. Because the City's service area cannot grow, the system's capacity should be adequate for many years to come.

In 2008, the City began an analysis of the water system with the objectives of reducing water waste and operating costs, and improving system reliability. The potential for a supervisory control and data acquisition (SCADA) project has been analyzed. This paper will discuss the analysis results and recommendations for improved water supply, treatment, and distribution, reducing spills and development of a SCADA project. Although the City has limited funding for system improvements, there are several low-cost measures that are being taken. For more costly measures, plans are being made in anticipation of funding from the 2009 Economic Stimulus Package.

INTRODUCTION

The City of Nevada City, California (City) is taking steps to improve its domestic water supply, treatment, and distribution system. The City, with a population of approximately 3,000, is located in Nevada County in the foothills of Northern California, and has a rich history dating back to the gold rush era in the nineteenth century (Figure 1). It is approximately 60 miles northeast of Sacramento and is in a heavily forested area at an elevation of 2500 feet. Today the City is a tourist destination, and the City and surrounding area are home to many retirees. As the county seat of Nevada County it is home to the county offices as well as the Forest Headquarters for the Tahoe National Forest.

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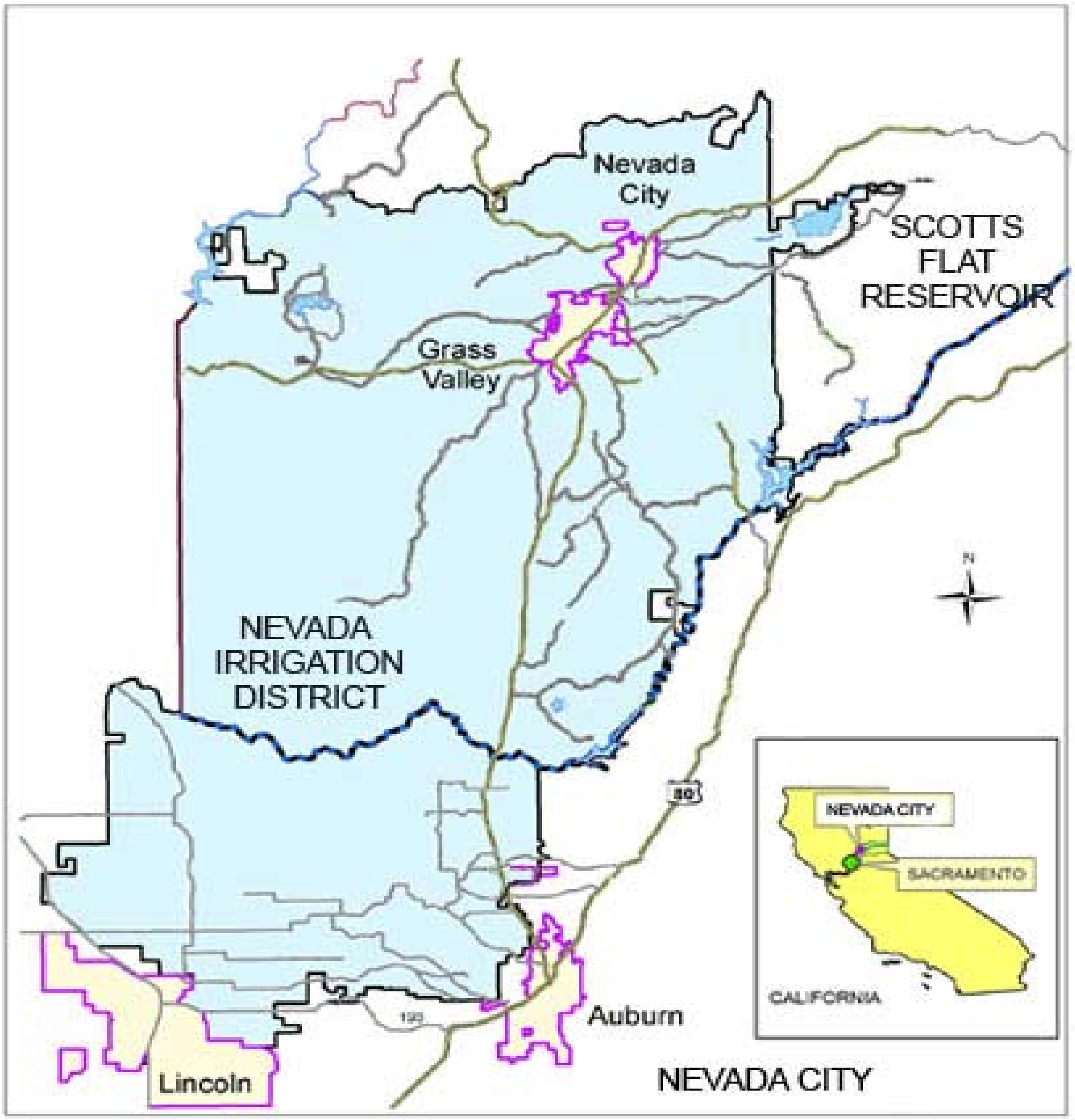

Figure 1. Nevada City Location

The Nevada Irrigation District (NID) covers 287,000 acres and was formed in 1921 to serve agricultural customers in Nevada and Placer Counties. NID has ten reservoirs on the western slope of the Sierra-Nevada Mountains with a total storage capacity of over 280,000 acre-feet. Water is conveyed to the service areas in 400 miles of canals and 300 miles of pipeline. NID provides treated and raw water to, municipal, residential, agricultural, and industrial water to customers throughout its service area. It currently supplies over 166,000 acre-feet of water annually, including about 150,000 acre-feet of irrigation water and about 16,000 acre-feet per year of treated domestic water. A recent study concludes that NID can meet the year 2027 predicted demand of 211,000 acre-feet per year.

In 2008, the City began an analysis of the water system with the objectives of reducing water waste, reducing operating costs, and improving system reliability. This paper will discuss the analysis results and recommendations for improved water supply, treatment, and distribution, reducing spills and development of a SCADA project. Although the City has limited funding for system improvements, there are several low-cost measures that are being taken. For more costly measures, plans are being made in anticipation of funding from the 2009 Economic Stimulus Package.

WATER SUPPLY SYSTEM

Water Supply

The City's primary water supply comes from two sources; natural runoff of Little Deer Creek, and raw water purchased from NID and delivered from the D-S Canal (Figure 2). There are no flow records on Little Deer Creek. The drainage basin covers 1,084 acres and precipitation averages about 55 inches per year; annual flow is estimated at 1,500 to 2,500 acre-feet per year and most of the runoff occurs during the winter and spring months. Water from either of the two sources can be delivered directly to the water treatment plant or stored in a 54 acre-foot reservoir (Figure 2). The 12-inch diversion pipe from the creek is not metered; its capacity is estimated at 5 to 7 cubic feet per second (cfs). The diversions from NID are measured at the D-S Canal diversion point, are typically made at increments of 1 acre-foot per day, and typically occur during the months of May to October.

There is an intertie between the City and NID treated water distribution systems, which provides an emergency supply in case of a major fire or a shut-down of the water treatment plant. An additional intertie is planned.

Water Demand

Over the past few years water use has averaged about 740 acre-feet per year, or 0.66 million gallons per day (mgd). The average use is about 220 gallons per capita per day (gpcd), which is typical for use in California where significant conservation measures have not yet been implemented. Peak use has been less than 1.40 mgd, well within the treatment plant's design capacity of 2.0 mgd. Because the City's service area cannot grow, the system's capacity should be adequate to serve city infill projects (new development on vacant land) well into the future. Water delivered to customers is metered; however a flat-rate is charged for use up to 25,000 gallons per month, and meters are read every three months.

Water Treatment Plant

The City's water treatment plant, completed in 1979, is a complete water treatment facility with a design capacity of 2.0 mgd. The processes include flocculation, clarification, filtration, disinfection, and pH control. The treatment plant has two independent sides (Side A and Side B); each side being capable by design of treating 1.0 mgd while the other side is shut down during periods of low demand or for needed maintenance or repair. Treatment Plant characteristics are given in Table 1.

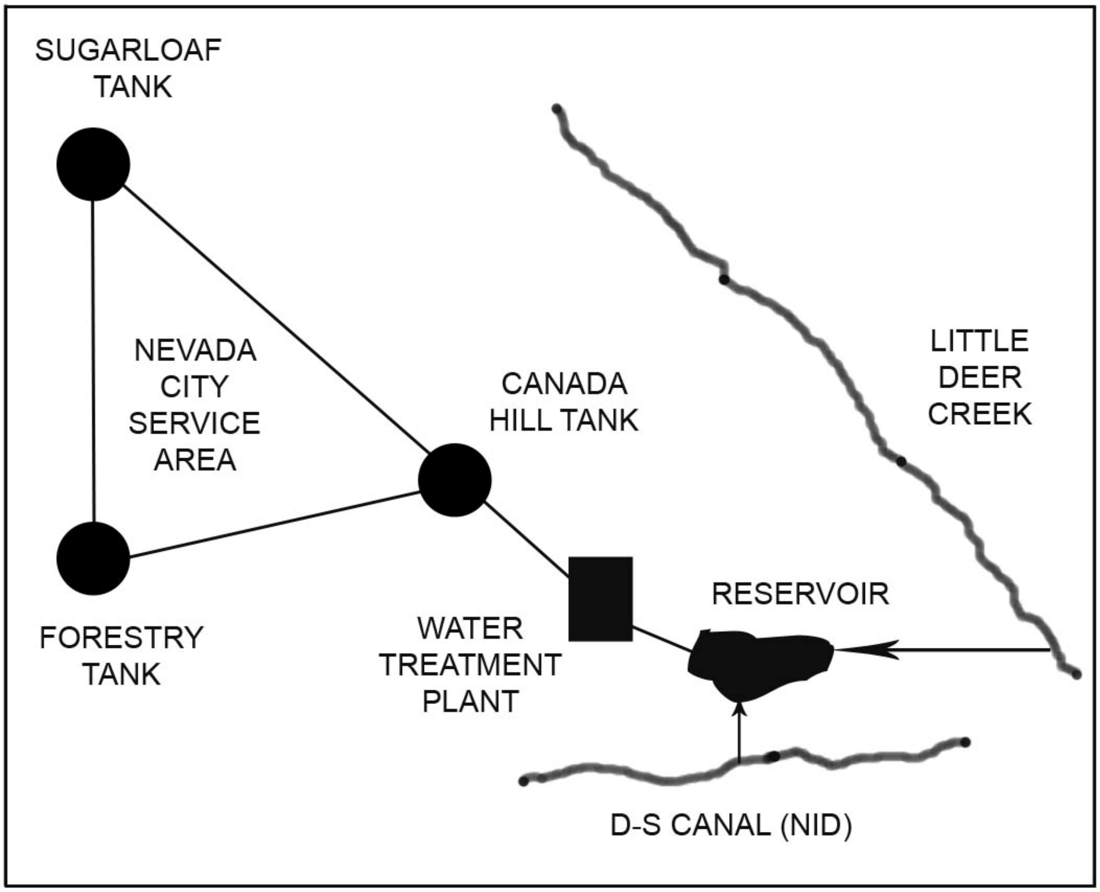

Figure 2. Nevada City Water System

Table 1. Treatment Plant Characteristics

Elevation:	2,771 feet above sea level
Storage Reservoir	54 acre-feet
Capacity, by design	2.0 mgd
Flocculator Capacity	57,560 gallons (28,780 each for Sides A and B)
Clarifier Capacity	86,400 gallons (43,200 each for Sides A and B)
Filter Type and Media	High rate gravity, dual media anthracite/sand
Filter Size	342 square feet (171 sf each for Sides A and B)
Filter Rate	4.06 gpm for 2.0 mgd capacity
Filter Backwash Rate	20.0 gpm/sf
Backwash Water Storage Tank	10,000 gallons

Liquid aluminum sulfate (alum) is added to the plant influent as a coagulant. Lime is added to the plant influent for pH control, and to the finished water for corrosion control. Chlorine is added as a disinfectant at three points; plant influent, filter influent, and plant effluent. Treated water is delivered to the City storage tanks and distribution system.

Storage and Distribution System

The treated water storage system consists of three storage tanks which surround the City (Figure 2). The total storage capacity is 3,000,000 gallons and the top elevation of each tank is 2,714 feet. With the treatment plant discharge at elevation 2,771 feet, the tanks and almost the entire distribution system is served by gravity.

The water distribution system consists of pipes ranging in size from 4 inches to 18 inches diameter. Some of the pipes are over 100 years old, and there are several bottlenecks in the system that restrict deliveries and cause the three storage tanks to fill at different rates. Under current operation the Canada Hill Tank is kept full and its valve is shut off to avoid spilling water. The Sugarloaf Tank is approximately 3 miles from the water treatment plant and cannot be filled without spilling water at the Forestry Tank.

SYSTEM IMPROVEMENTS

Water Supply

Water supply improvements include better measurement and better management of the water supply. A staff gage will be installed on Little Deer Creek at the City's diversion to begin to develop some stream flow data to better determine how much runoff to expect in years of varying rainfall. The gage will be read at least once a week when the diversion is visited during the high runoff season.

A flow meter should be installed on the diversion pipe, and together with the measurement of flow from the D-S Canal will show how much total water supply is being delivered to the system. A level transducer at the reservoir will show the change in storage and with the above readings will determine how much water is being delivered to the water treatment plant.

Better management of the reservoir will maximize the water supply from Little Deer Creek and minimize the amount of water needed to be purchased from NID. Past operation of the reservoir has been to keep it near full at all times. Drawing down the reservoir 8 feet in the fall will allow additional storage of about 25 acre-feet of water from Little Deer Creek during the high runoff season. The spillway has a capacity of 600 cfs. Since the reservoir's drainage basin is very small, only a catastrophic failure of the D-S Canal could result in flows this high.

NID diverts water from Little Deer Creek to its Cascade Canal above the City's diversion. Except for the NID releases from the D-S Canal to the City's reservoir, there is no coordination of operations on Little Deer Creek. Coordinating the operations of the two entities could result in maximizing the water supply from the creek.

Water Treatment Plant

There is a large difference in the metered treatment plant inflow and outflow which appears to be due to inaccuracies in the metering equipment. In 2007, the apparent difference varied from 75,500 gallons per day in February to 363,500 gallons per day in August and has averaged almost 200,000 gallons per day. By comparing the treatment plant inflow and outflow readings with water purchases from NID and estimated diversions from Little Deer Creek, it appears that the inflow readings are unrealistically high. A review of process water for backwashing losses, chemical analysis, restroom use, etc. showed that the "lost water" should only be on the order of 5,000 to 10,000 gallons per day, unless there are large unknown leaks in the plant piping, which appears unlikely. The orifice meters on the treatment plant inflow lines (Side A and Side B) should be recalibrated or replaced with electronic flow meters. Treatment plant outflow is measured by a meter located in the pipeline below the Canada Hill Storage Tank, which is not now operated on a daily basis and is kept full. With other system improvements described in the following section, the Canada Hill Storage Tank will be operated daily, and a flow meter should be installed on the Treatment Plant outlet pipe.

The treatment plant has two filter basins that are operating at much less than their design capacity. Backwash water from the filter basins was stored in two small holding ponds and then recycled to the flocculation basins, recycling fine material to the filtration basins. The treatment plant piping has been modified so that backwash water flows first to an unused sludge storage pond, increasing the detention time prior to recycling to the flocculation basin. The anthracite filter media has not been replaced in over 20 years, and has broken down to the point that backwashing is required on a daily basis. The City is planning to replace the filter media in May 2009, at a cost of about $43,000. Upgrading the filter underdrains would increase the filtering capacity and would cost about an additional $100,000; however due to budget constraints this additional work is not being considered at this time. The Treatment Plant automation system is 30 years old and needs to be upgraded and integrated with a SCADA system (described below). An up-to-date personal computer is also needed for improved record keeping, data analysis, and reporting.

In 2008 an operating manual was prepared to assist the water treatment plant operators in the operation and maintenance of the plant. The manual will be reviewed and updated annually.

Storage and Distribution System

There are several needed improvements to the City's storage and distribution system; including altitude valves at the three storage tanks, a SCADA system, replacement and/or additions to the pipe distribution system.

A water distribution system model (EPANET 2.0) was obtained and was used to analyze a simplified version of the City's water distribution system for current conditions and for several proposed improvements of the system. Model results should not be taken as absolute precise values; however they give a good approximation of current conditions and show how the system would react to changes. Model results are summarized below:

1. With the Canada Hill Tank full and not in daily operation (which is the current situation), The Forestry Tank spills before the Sugarloaf Tank can be filled. To avoid spills at the Forestry Tank the Sugarloaf Tank can only be filled as follows:
    a. 9.4 feet from the top at a flow from the water treatment plant of 1000 gpm (1.44 mgd), which is slightly higher that the maximum daily demand for the last few years.
    b. 6.1 feet from the top at a flow of 700 gpm (1.008 mgd).
    c. 2.5 feet from the top at a flow of 400 gpm (0.576 mgd).
2. Installing an altitude valve at the Forestry Tank (to shut off when the tank is full and open when the pressure in the pipe to the tank reduces) would allow the Sugarloaf Tank to be filled within 1.3 feet of the top without spilling at a flow of 1000 gpm. Adding this valve appears to be the most cost-effective near-term improvement to the distribution system, with adding altitude valves to the other two storage tanks in the future.
3. Adding a 12 inch pipe on South Pine Street would allow the Sugarloaf Tank to be filled within 2.8 feet of the top without spilling at a flow of 1000 gpm. Adding this pipe would give the system some needed redundancy.
4. Connecting the line on North Broad Street to the pipe feeding the Sugarloaf Tank would not significantly improve flow conditions to the Sugarloaf Tank; however it would give the system some needed redundancy.
5. Varying the water treatment plant flow throughout the day to more closely mirror demand did not appear to significantly improve system performance.

Recommended improvements to the storage and distribution system are as follows:

1. Install altitude valves at the three storage tanks. The valves will allow the tanks to be controlled to maximize storage and eliminate spills.
2. Install a SCADA system which links the three storage tanks to Water Treatment Plant and the Wastewater Treatment Plant, which is staffed for more hours than the Water Treatment Plant. The flow meters described in the water supply and water treatment improvement sections above should be incorporated in the SCADA system.
3. Install a 1,500 foot long, 12 inch pipe on South Pine Street to improve flow to the downtown area and give the system some needed redundancy.
4. Connect the line on North Broad Street to the pipe feeding the Sugarloaf Tank to improve flow to and from the tank and to give the system some needed redundancy.
5. Several pipes that are over 100 years old and have a roughness coefficient (RC) estimated to be 60 to 70 should be replaced, as well as the service lines to individual customers.

Water Conservation

The City installed water meters for each customer in 1978. Meters are read every three months; and a flat-rate is charged for use of up to 25,000 gallons per month. An analysis of water use could identify the largest water users and determine if any conservation measures will result in significant water savings. Saved water would result in reduced purchase of water from NID and less cost for water treatment. Saved water would also provide a supply for new customers in the City's existing service area. A water rate study could determine if the City's water-rate structure is compatible with other small cities and is conducive to water conservation.

Cost Savings

The cost for raw water purchased from NID is currently $193 per acre-foot and chemical costs for water treatment are about $24 per acre-foot. Any water saved from system improvements and water conservation would significantly reduce operating costs. For example, a reduction in water use of 100 acre-feet per year would result in a cost savings of over $20,000 per year.

Funding for Needed Improvements

The City has budget constraints and is limited to fund low cost and critical improvements; including installing a staff gage at Little Deer Creek, improved management of the reservoir, better coordination with NID, recalibrating the flow meters for the treatment plant inflow, and replacing the filter media at the treatment plant. When funds become available, an altitude valve should be installed at the California Division of Forestry Tank to better manage the storage and distribution system.

The City has applied for over $4,500,000 of funding from the 2009 Federal Economic Stimulus Package, of which about $775,000 is for improvements to the water system. As of mid-April 2009, only $116,000 for street improvements is assured. If more stimulus funds become available, the City should install underdrains under the treatment plant filters, new flow meters to more accurately measure water flow, altitude valves at the remaining two storage tanks, a SCADA system, and replace and add to pipes in the distribution system. Under a separate Federal program, the City has applied for a Community Development Block Grant to conduct a water rate study.

CONCLUSION

In 2008, the City of Nevada City began an analysis of its water system with the objectives of reducing water waste and operating costs, and improving system reliability. Although the City has limited funding for system improvements, there are several low-cost measures that are being taken; including; improved operation of the water treatment plant, monitoring and better prediction of available water supplies, and reducing spills in the water distribution system. For more costly measures, plans are being made in anticipation of funding from the 2009 Federal Economic Stimulus Package and a Federal Community Development Block Grant. These measures include development of a

SCADA system, replacement and improvements to the storage and distribution system, and a water rate study. These measures will ensure that the City's water supply system will be adequate and reliable far into the 21^{st} century.

SYSTEM OPTIMIZATION REVIEW FOR THE POSO CREEK INTEGRATED REGIONAL WATER MANAGEMENT PLAN REGION

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R. Iger[3]
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P. Oshel[5]

ABSTRACT

This paper provides an overview of the Poso Creek Integrated Regional Water Management Plan (IRWMP or Plan) and the System Optimization Review (SOR) being conducted for the Plan's Region. SORs are a component within the U.S. Bureau of Reclamation's *Water for America* program.

The Region contains six agricultural water districts with about 350,000 of irrigated cropland out of a gross area over 500,000 acres. The managed water supplies for the districts include:

- ✓ Local: Kern River, Poso Creek, and the common groundwater basin
- ✓ State: State Water Project via the California Aqueduct
- ✓ Federal: Central Valley Project via the California Aqueduct and the Friant-Kern Canal

The recent regulatory and hydrologic droughts in California are causing a decrease in water reliability of the managed supplies available to the Region. The result is a projected average annual loss of supply to the Region, which has brought this group of districts together to leverage their individual water supply and infrastructure assets as a *region*. Since the Region is located at the "crossroads" of the California Aqueduct, Friant-Kern Canal, and the Kern River, it is an ideal location for regional conjunctive management.

The SOR is to (1) prioritize the implementation of structural water management measures for the Region, and (2) identify and resolve institutional constraints to exchanges between districts and thereby enhance the use of available district groundwater banking capacity and facilities. Conducting the SOR enhances the districts' shared approach to Plan implementation and sound stewardship of the Region's surface water and groundwater resources.

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[5] District Engineer, Semitropic Water Storage District, Wasco, CA

INTRODUCTION AND BACKGROUND

The Poso Creek Region is located in north Kern County and southern Tulare County of the Southern San Joaquin Valley, California as shown in Figure 1. It is a rich agricultural area with a crop value in 2009 expected to be on the order of $2 billion. The rich soils, climate, and irrigation water make it possible to grow a variety of crops, with the largest value crops being almonds, pistachios, vegetables, alfalfa, and grapes, which are sold worldwide.

The Regional Water Management Group (RWMG) was formed in March, 2005, and includes six special districts and one resource conservation district. The RWMG is an experienced group of water managers.

- Semitropic Water Storage District – Lead Agency
- Cawelo Water District
- Delano-Earlimart Irrigation District
- Kern-Tulare Water District
- North Kern Water Storage District
- Shafter-Wasco Irrigation District
- North West Kern Resource Conservation District

The RWMG completed and adopted an Integrated Regional Water Management Plan in July 2007. The RWMG, Stakeholders, and Plan Participants continue to meet monthly to coordinate Plan implementation activities.

The purpose of the Plan is to provide a framework for (1) coordinating groundwater and surface water management activities through regional objectives, and (2) implementing the measures necessary to meet those objectives.

The RWMG districts overlie a common groundwater basin identified by the California Water Resources Control Board as the Poso Creek Hydrologic Unit of the Tulare Lake Basin Hydrologic Area located in the northerly portion of Kern County and southerly portion of Tulare County. All communities within the Region rely on the common groundwater basin for their drinking water supply. Environmental water users rely on the same common groundwater and surface water supplied from the same sources as the districts who deliver water for irrigation.

The Region has a very unique location regarding water supply and this is a very valuable asset, not only to the Region but to California. The assets include a very large groundwater basin, with surface water from several sources, including Poso Creek, Kern River, the Federal Central Valley Project (CVP), and the State Water Project (SWP).

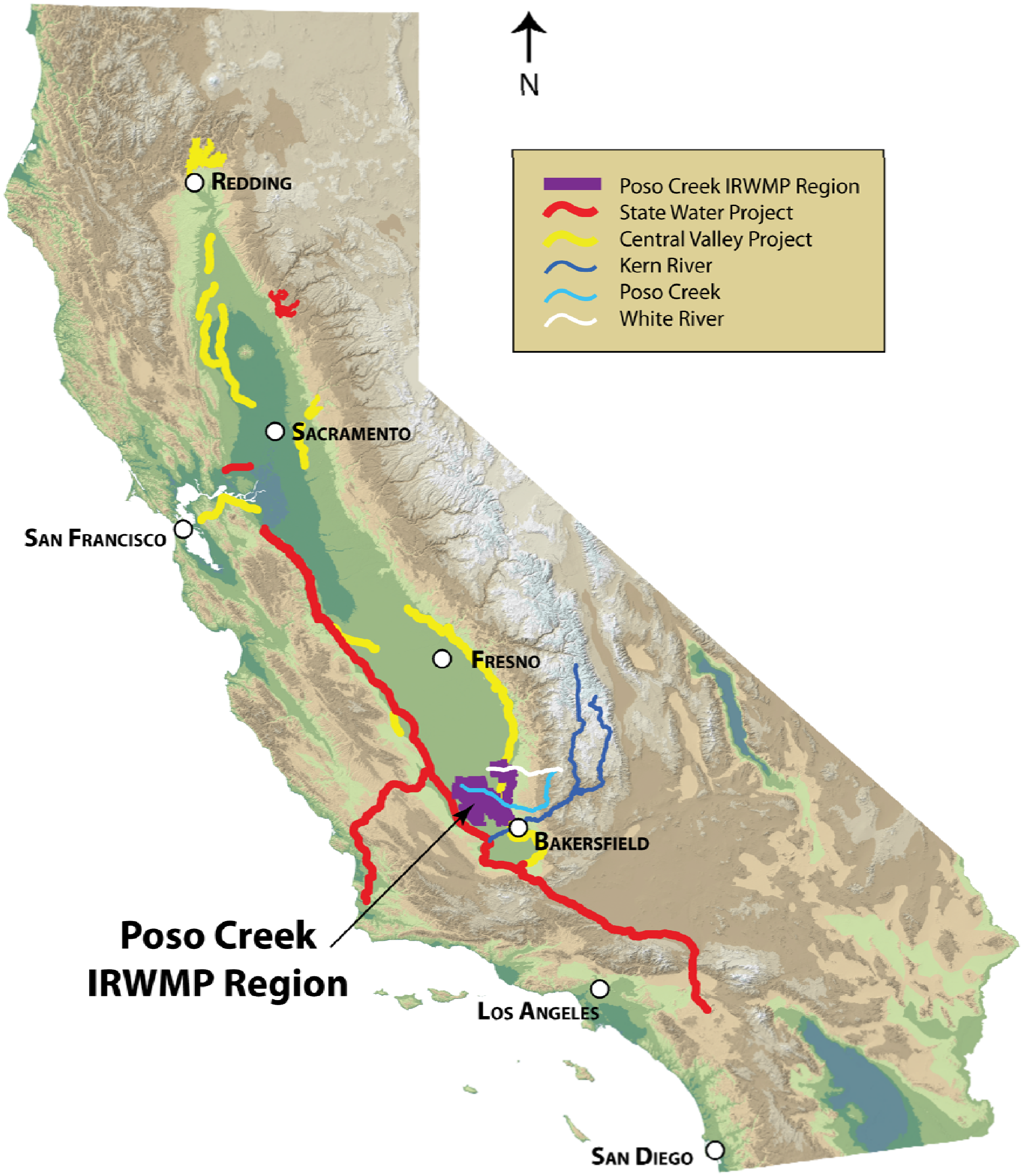


Figure 1. Location of Poso Creek IRWMP Region

The reliability of the surface water supplies available to the Region are under attack. Water reliability of the managed supplies available to the Region has or will decrease due to (1) the court-ordered reduced pumping south of the Sacramento-San Joaquin Delta, (2) implementation of the San Joaquin River Settlement, which affects the timing for delivery of CVP supplies, (3) storage restrictions imposed by the Corps of Engineers on Isabella Reservoir to address dam safety issues that will reduce the capacity to regulate Kern River supplies during wet years, and (4) the expiration of long-term Kern River water supply contracts.

Upon meeting as a group, it became apparent that the reliability of water supply can be increased by operating cooperative programs among the districts. The primary goal is to increase the sharing of facilities and sources of supply so that when water is available, the maximum quantity of surface water can be absorbed in the area to replenish the groundwater. With the three principal surface water sources, this can be accomplished by cooperation, joint use of facilities, added interconnections, and institutional agreements.

Because the RWMG members share the common features and interests, water management programs can be accomplished which help to meet their overarching goal of making water supplies to the Region more reliable. Several water banking and exchange agreements have been accomplished as a result of the interconnections and communications afforded by the Plan feasibility studies and forums. Specific examples include moving wet-year water into areas that have extra absorptive capacity in order to get water back in future dry years.

PLAN FINDINGS AND CONCLUSIONS

While the Plan includes a number of findings, the overriding conclusion is that surface water supplies available to the Region will be significantly reduced in the future (relative to historical conditions) and that there will be a corresponding decline in groundwater levels as groundwater is used to make up the reduction in surface water supplies if actions are not taken. This decline will result in an increase in the use of power and energy resources to pump groundwater, creating both an environmental and economic burden. This economic burden will be felt by <u>all</u> uses that rely in whole or in part on pumped groundwater — whether agricultural, environmental, municipal, or industrial. While the *common groundwater basin* is the reason that all overlying uses will feel the impact, it is also the reason that anything that is done to offset declines in water levels, such as projects identified in the Plan, will benefit all uses. As a generalization, the Plan contemplates projects, both structural and non-structural, that will allow the agencies within the Region to maximize the use of their contract water supplies and other supplies that may be available from time to time. In particular, these projects provide the means for coordinating the assets, needs, and operations of the agencies within the Region, with the end result being improved *water supply reliability*.

The *findings and conclusions* include …

- ✓ The Region has a water supply problem (with the long-term average annual reduction in surface water supplies projected to be on the order of 100,000 acre-feet).
- ✓ By working together, the problem can be reduced but not eliminated, at least with currently available supplies.
- ✓ The Regional Water Management Group is the right forum for working together.
- ✓ Priority should be given to enhancing conveyance between and within districts.
- ✓ Both structural and non-structural measures are required.
- ✓ Non-structural measures include …
    - An organizational structure and environmental compliance framework that allows for exchange and banking approvals to be in place to take advantage of unregulated and unscheduled water supplies that are available from time to time, often on short notice.
    - The necessary environmental and institutional approvals to move water from different sources within the Region; these approvals are required to maximize the utility of the Region's assets and thereby maximize water supply and reliability to the Region.
    - A means of maintaining equity between districts within the Region, in terms of water and/or dollars.
- ✓ Structural measures include one or more connections between …
    - The Calloway and Lerdo canals.
    - North Kern Water Storage District and Shafter-Wasco Irrigation District.
    - Shafter-Wasco Irrigation District and Semitropic Water Storage District.
    - The Calloway and Cross Valley canals.
- ✓ Need to maximize use of available surface water supplies through the use of existing absorptive capability by coordinating mismatches between supply and demand with the Region, i.e. matching supply that exceeds demand in one district with demand that exceeds supply in another district. This applies to both irrigation absorptive capability as well as spreading absorptive capability.

- ✓ Consider development of additional third-party water-banking arrangements that bring more water into the Region than the Region is obligated to return (such as is the case with an unbalanced banking program) and/or bring dollars into the Region that can be used to help purchase waters of opportunity and/or build new distribution and recharge capability.

- ✓ Support improving water supply reliability from the Sacramento-San Joaquin Delta.

- ✓ Support implementation of the *water management goal* of the San Joaquin River Settlement.

- ✓ Support the restoration of lost capacity in the Friant-Kern Canal as well as expanded capacity, in order to maximize the use of contract supplies.

PLAN IMPLEMENTATION AND SYSTEM OPTIMIZATION REVIEW

The RWMG formulated and prioritized projects to implement within the Region, consisting of both non-structural and structural water management measures. Locations of the structural measures and the status of each proposed water management measure are indicated on Figure 2.

The purpose of the System Optimization Review (SOR) is to further evaluate the water management measures identified in the Plan. The SOR builds on the initial assessment of the water management improvements presented in the Plan, which included both non-structural and structural measures.

Through the following tasks, the SOR is designed to move Plan implementation forward.

- working to resolve the non-structural, institutional constraints that now hinder long-term water exchanges and banking of state and federal water supplies available to the Region,

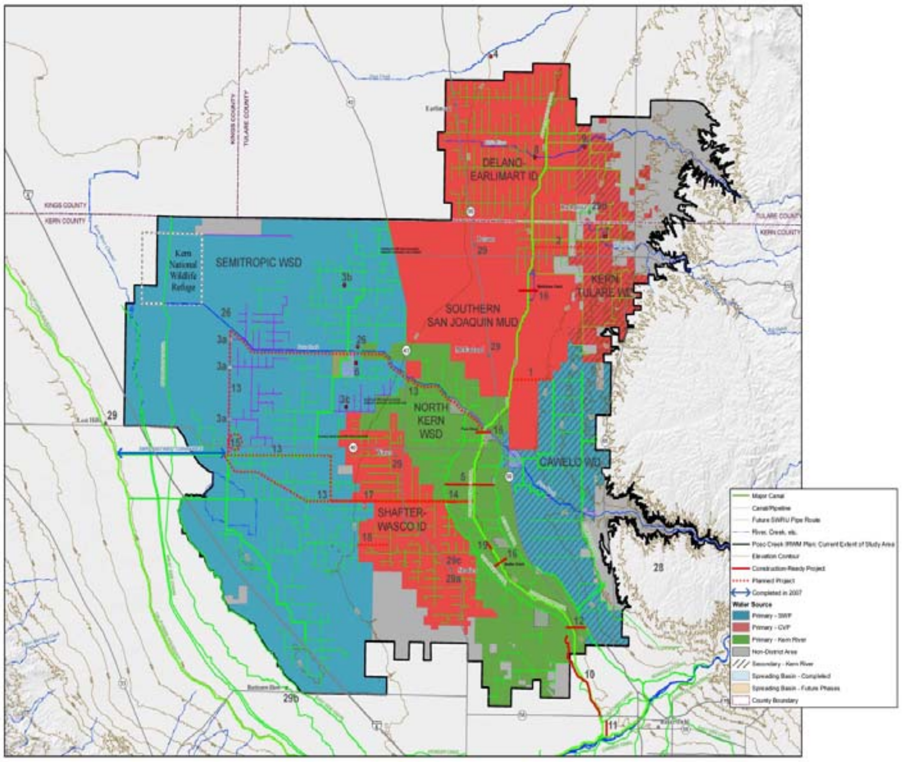
- improving the quantification of benefits, in terms of the amount of water that non-structural measures and individual structural projects can provide to the Region, and

- evaluating the cost of each individual project.

SUMMARY

- Water supply reliability and potential for conflict within the Region have worsened due to recent events, such as the federal court order restricting pumping south of the Sacramento-San Joaquin Delta. The RWMG is faced with re-regulating their local, state, and federal water supplies in an effort to reduce the

Proposed Non-Structural and Structural Water Management Measures



P = In Progress C = Construction Complete
D = Planning/Preliminary Design S = Shovel-Ready for Construction

Structural Projects (Locations Shown on Map)

Expand In-Lieu Service Areas
- D 1 Connect Friant-Kern Canal Turnout to Cawelo's North System
- D 2 Ninth Avenue Pipeline
- S 3a Stored Water Recovery Unit
- C 3b Expand P-1030 In-Lieu Service Area
- C 3c New P-565 In-Lieu Service Area

Expand Direct Recharge
- D 4 G-W Banking North of DEID with Pixley ID
- D 5 G-W Banking Conveyance Improvements to North Kern WSD Recharge and Recovery Facilities
- S 6 Pond Poso Spreading Grounds
- D 7 Rag Gulch G-W Banking Project
- S 8 Turnipseed GW Banking Project Enhancement along White River in DEID
- D 9 White River G-W Banking in Rag-Gulch

Modify Conveyance Systems
- S 10 Calloway Canal Improvements
- S 11 Calloway Canal to Cross Valley Canal Interconnection
- S 12 Calloway Canal to Lerdo Canal Interconnection
- D 13 Multi-District Conveyance Facility
- S 14 North Interconnection between North Kern WSD/Shafter-Wasco
- D 15 Pilot Arsenic Treatment Plant
- D 16 Reverse Flow in the Friant-Kern Canal
- D 17 Shafter-Wasco/Semitropic Interconnection on Kimberlina Road
- D 18 Shafter-Wasco/Semitropic Interconnection on Madera Avenue
- S 19 South Interconnection between North Kern WSD/Shafter-Wasco

Non-Structural Projects (some locations not shown on map)
- P 20 Energy Usage
- P 21 Joint Powers Authority
- P 22 Institutional Agreements and Governance for IRWMP Implementation
- P 23 GW Banking for Parties Outside of Poso Creek IRWMP Region
- P 24 Optimizing Region's Pumping Lifts
- P 25 Enhance Groundwater Monitoring and/or Modeling

Enhance Environmental Resources
- D 26 Wildlife Improvement Projects in IRWMP Region
- D 27 Environmental Water Management in Support of Wildlife Settlements Outside of IRWMP Region

Enhance Flood Control
- D 28 The Poso Creek Flood Control and Water Conservation Reservoir Project

Assist Economically Disadvantaged Communities
- D 29 Enhance Water Supply, address Drinking Water Treatment Needs, and upgrade Waste Water Treatment Faciliites

Figure 2. Proposed Water Management Measures

impacts of these events on the common groundwater basin. The RWMG is concerned with maintaining water supply reliability as they respond to the following issues:

- court-ordered reductions on pumping South of the Sacramento-San Joaquin Delta,

- San Joaquin River Settlement, and
- storage restrictions imposed by the Corps of Engineers on Isabella Reservoir (which regulates Kern River water) to address dam safety issues.

All of these concerns lead to a loss of surface water supply to the Region as compared to their historical use of supplies. These concerns also lead to an increased capital cost for additional infrastructure needed to manage wet-period water supplies and an increased operating cost due to increased energy use to lift groundwater to match the timing of the crop's water demand. The districts are faced with implementing water management measures to help offset the loss of their surface supplies. The loss of their surface supplies will lead to a lowering of the water table as the region goes out of "balance" in comparison to the historical, 25-year period of equilibrium between surface water supplies and groundwater elevations. Reductions in surface water inflow results in increased demand on and reduced recharge to the common groundwater basin.

The *Water 2025 SOR for the Poso Creek IRWM Plan Region* is building upon the water supply operations study conducted in the Plan. The Plan's operations study evaluated the existing absorptive capacity of each district – the capacity of each district to utilize or store available surface water. Based on the above-mentioned water supply issues, the operations study projected a loss of surface water supply to the Region of over 100,000 acre-feet per year in comparison to the previous 25-year period; this assessment was prior to Judge Wanger's decision of September 2007, that significantly, further reduced pumping south of the Sacramento-San Joaquin Delta.

During the Poso Creek Plan formulation and monthly discussions, two common themes emerged:

- a sense of shared responsibility on the part of the member districts and the RWMG for sound stewardship of the Region's surface water and groundwater resources, and
- recognition that water management conflicts can only be avoided through regional collaboration and cooperation with the larger Valley-Wide planning effort for the Southern San Joaquin Valley and with state and federal agencies.

The RWMG recognizes that water management improvements and institutional changes will take time. Offsetting the projected loss of surface water supply to the Region and avoiding future conflict is the driving force that has brought the RWMG together and is the shared focus as they implement their Plan. The planning and implementation efforts have succeeded in bringing the district managers together on a regular monthly basis to discuss water management operations under both wet-year and dry-year conditions. The result of this dedicated communication is a collection of water management strategies that are being implemented as funding permits.

Conducting the SOR allows the RWMG to work towards resolving the institutional constraints and to evaluate system operations in more detail as they implement the water management measures. It also allows the RWMG time to refine the quantities of water to be developed by each water management measure for use in more detailed economic evaluation of each project.

WATER SYSTEM OPERATOR TRAINING FOR THE CENTRAL ARIZONA PROJECT

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ABSTRACT

The Central Arizona Project (CAP) is designed to bring about 1.5 million acre-feet of Colorado River water per year to Maricopa, Pima, and Pinal counties in Arizona. CAP carries water from Lake Havasu down to Tucson. The CAP canal system is a 336-mile long system of aqueducts, tunnels, pumping plants, and pipelines and is the largest single resource of renewable water supplies in the state of Arizona. The entire CAP system is monitored and remotely controlled using Supervisory Control and Data Acquisition (SCADA) software from CAP headquarters in Phoenix, AZ. Recently, several new SCADA operators have been hired by CAP. The new operators received SCADA training only by observing the more experienced operators manage the canal system and thus their training was driven by the day-to-day operation of the system. To better equip their new Water System Operators, personnel at CAP recently commissioned the development of a new SCADA training tool as envisioned by researchers at the U.S. Arid Land Agricultural Research Center that replaces the real canal with a hydraulic simulation model without making any changes to the SCADA software. Employees at WEST Consultants, Inc. recently modified this training tool so that it works with HEC-RAS as the hydraulic simulation model. Using this new training tool, the new CAP Water System Operators are now being trained to operate the CAP system under a much wider range of flow conditions and emergency situations without endangering the actual canal system or wasting water. The training tool will give the new operators a larger knowledge base with which to handle emergency situations.

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INTRODUCTION

The Central Arizona Project

The Central Arizona Project (CAP) is Arizona's largest renewable water supply and was constructed to help the state conserve its groundwater by importing surface water from the Colorado River. CAP was designed to deliver an average of 1.5 million acre-feet of water to residents of Maricopa, Pima, and Pinal counties (see **Figure 1**). CAP delivers untreated water to three major types of customers: municipal and industrial, agricultural, and Native American users. The customers are then responsible for their own water treatment. The CAP canal travels 336 miles across the state of Arizona. The canal begins at Lake Havasu, continues through the Phoenix metropolitan area, and ends in Tucson. CAP consists of 14 pumping plants, 1 pump/generating plant, 10 siphons, 3 tunnels, and more than 45 turnouts for customer deliveries. During its travels across the state of Arizona, water is pumped more than 2,800 vertical feet and flows through the canal via gravity following the natural contours of the land. Construction of the system began in 1973 and was substantially complete in 1993.

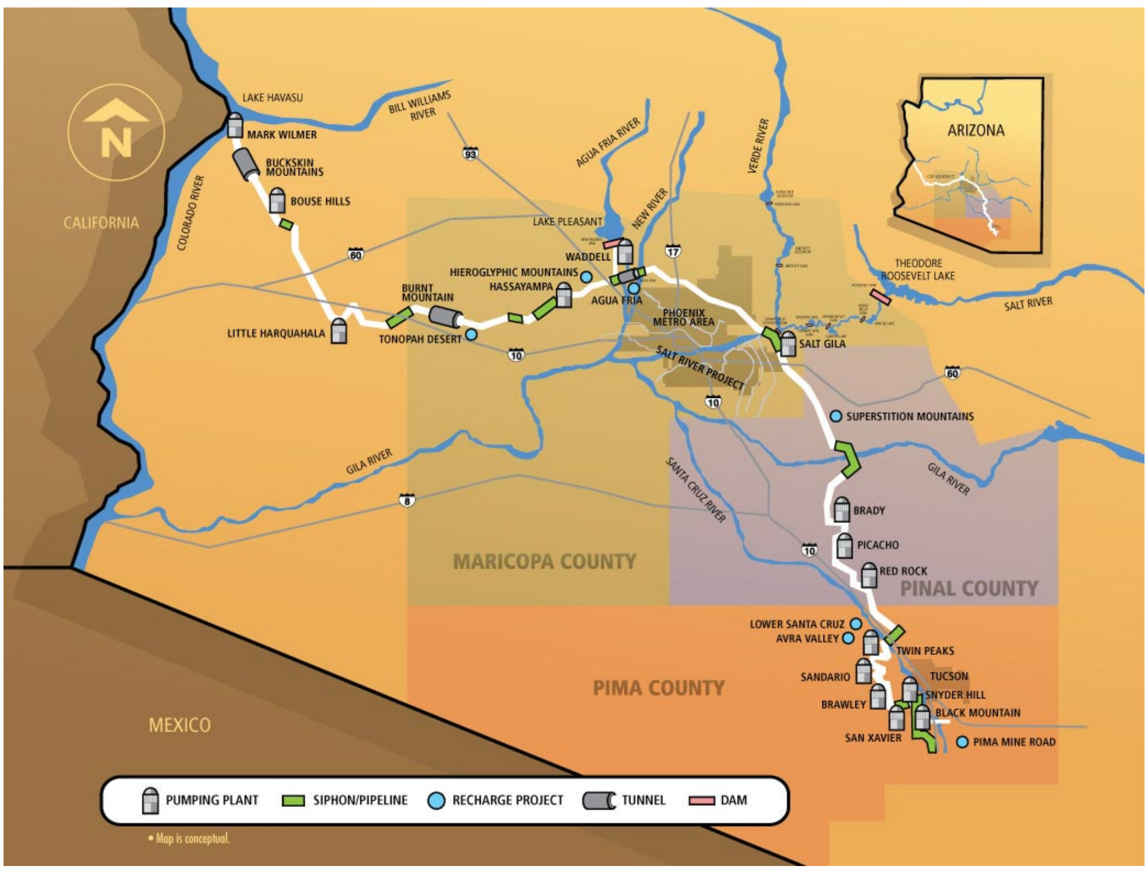

Figure 1. Schematic Diagram of the CAP Canal System

Central Arizona Project's Control Center

The entire CAP canal system is remotely monitored and controlled via a Supervisory Control and Data Acquisition (SCADA) system from CAP's Control Center, located at CAP headquarters in Phoenix, AZ. Real time data from the entire CAP canal system is transmitted to the CAP's headquarters and displayed on various computer screens (a typical SCADA screen is shown in **Figure 2**). Information displayed includes water levels in the various pools, gate positions, flow rate estimates through structures, turnout deliveries, and pump status (e.g., on, off, or failed). There are more than 1,000 real time SCADA displays that the operators can use to assist in the operation of the system. At any given time, 8 billion gallons of water is managed from the Control Center, which is staffed by at least 2 Water System Operators 24 hours a day, 7 days a week.

The main goal of the CAP Water System Operators is to effectively route flow changes through the canal system in order to meet customer demands without causing fluctuations in water levels that could disrupt service to other customers or potentially overtop and damage the canal. The Water System Operators have various tools at their disposal with which to operate the canal system. The Water System Operators can:

1. Turn pumps on or off
2. Move gates up or down
3. Change customer deliveries

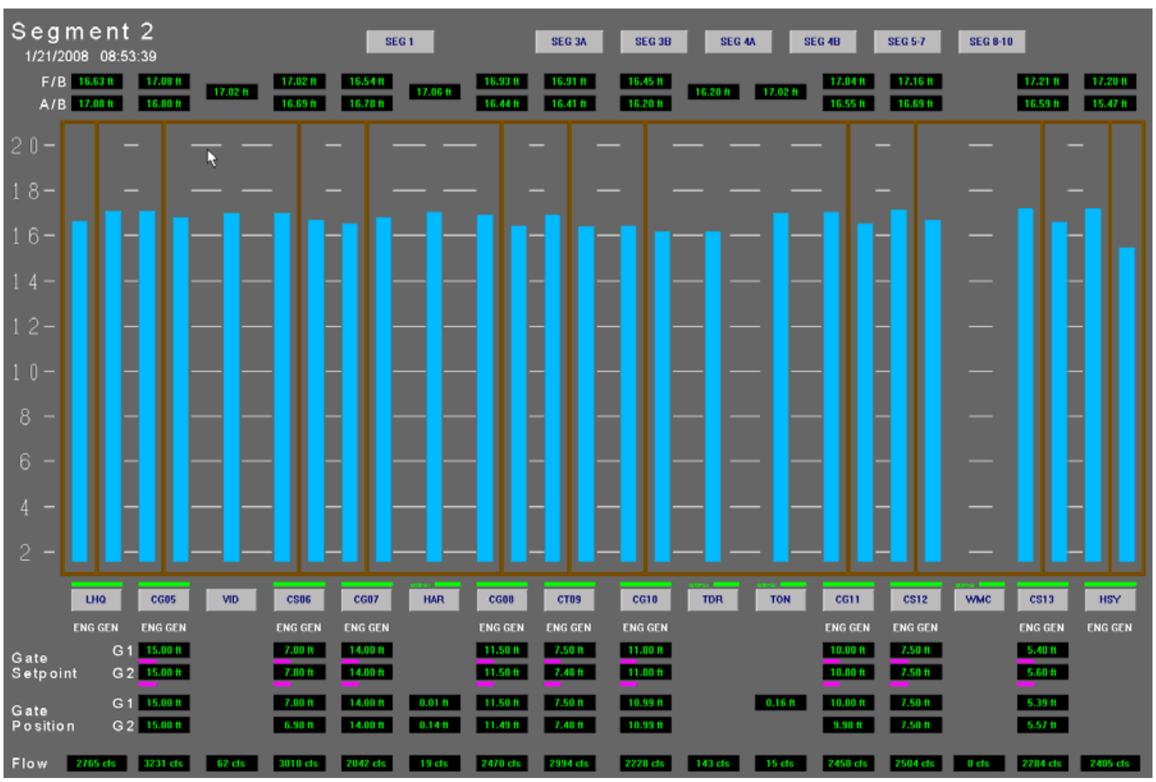

Figure 2. Typical SCADA Screen for CAP (bars indicate water depths)

COMPLEXITIES IN OPERATING OPEN-CHANNEL SYSTEMS

Initially, operating an open-channel system like CAP may appear to be fairly straightforward because, for any pool in the system, the inflow into the pool equals the outflow from the pool plus the change in storage volume over time. However, there are many aspects of open-channel flow that make the operation of the system more difficult than it first seems:

1. Operators must handle unscheduled changes in demand, which can arise from check structure failures, pump failures, vandalism, or other emergency situations.
2. Operators must deal with safety concerns. Obviously, overtopping the canal can cause serious damage to the canal system. In addition, lowering the water surface too quickly can cause structural damage to the canal lining.
3. Operators must deal with the uncertainties inherent in the canal system. Operators do not exactly know properties of the system such as flow rate, stage measurements, and roughness. If left unaccounted for, these uncertainties cause the water deliveries to be different than desired.
4. Operators must deal with transient effects that characterize unsteady flow such as delay times, dispersion effects, changes in storage volume, and hydraulic interactions between the pools.
5. Operators must rely on experience to effectively operate an open-channel system. Even after learning how to manage the canal, operators may not be able to handle emergency situations effectively because these scenarios were never addressed in their training.

Because of the importance, difficulty, and complexity of operating an open-channel canal system like the CAP, Water System Operators require a significant amount of training before they can effectively manage the system.

SCADA Systems and Open-Channel Systems

SCADA systems are very popular in manufacturing plants and municipal water delivery systems. However, there are several irrigation districts that currently use a SCADA system to monitor and control their open-channel systems. Some of these irrigation districts with SCADA systems include the Central Arizona Project, the Salt River Project, Imperial Irrigation District, Maricopa-Stanfield Irrigation and Drainage District, and Central Arizona Irrigation and Drainage District.

SCADA Training at the Central Arizona Project

Typically, new Water System Operators at CAP are required to complete up to 18 months of training and supervision before they are allowed to operate the canal system independently. Even after this training period is complete, the Water System Operators' training will have been limited to day-to-day operations. The newly trained Water System Operators will have little experience operating the canal under a wide range of flow conditions. The new operators will also have little training on how to operate the canal under emergency conditions, since setting up a real world emergency training scenario would put the canal system at risk or interrupt water deliveries.

Additional Difficulties with SCADA Training

Strand et al. (2005) lists several problems associated with the SCADA training at typical irrigation districts. Some of these issues do not apply to the CAP but are common in smaller irrigation districts. These problems are summarized in the following paragraphs. First, the Water System Operators employed by many irrigation districts can come from a wide variety of backgrounds and have varying levels of canal experience. For example, at the Salt River Project (SRP), a very large organization, operators generally work their way through the hierarchy of the canal operations system. Most start as a zanjero and eventually work their way to the control room. Through this experience, they gain working knowledge of system topology, pool transmission delays, problem check structures, etc. This knowledge is invaluable once they are in the control room. While smaller organizations do promote some field operators to SCADA operator positions, these smaller districts are sometimes forced to hire SCADA operators with little or no canal operation experience.

Second, regardless of the level of applicable canal experience, the learning curve for a SCADA system can be quite steep, especially for an operator with limited computer experience. Some homegrown SCADA systems run essentially as embedded systems, meaning that the only software available on the computer is the SCADA software. With modern Windows-based SCADA systems, these computers can allow the operator to use other tools, such as email, databases, billing, and accounting software on the same computer. Many operators require some training to gain familiarity with a networked computer environment as well as managing other duties in conjunction with operating the canal.

Finally, SCADA operators are also trained in a “live” environment while operating a real canal. At CAP and SRP, the environment is generally focused on running the canal system. There are separate departments that handle ordering, billing, and payment receipts. At smaller irrigation districts, like the Central Arizona Irrigation and Drainage District (CAIDD), the canal operators handle all of those financial/clerical tasks in addition to operating the canal. For those with little or no canal experience, the distraction of dealing with the business functions can be overwhelming and can hinder progress in understanding the canal system from an operational perspective.

SCADA TRAINING TOOL FOR CAP

Effective operation of the canal system is imperative at CAP from both a safety aspect and a customer satisfaction aspect. Water System Operators must learn how to efficiently utilize the tools at their disposal in order to effectively route water to their customers. In an effort to have more robust training of their Water System Operators, CAP commissioned the development of a training tool that allows their Water System Operators to be trained on a hydraulic model of the canal instead of the real canal. Using this system, Water System Operators can be trained to operate a canal system under a wide range of emergency situations without endangering the actual canal system, interrupting customer deliveries, or wasting water. This training tool was developed for Segment 2 of the CAP canal system, which stretches 62 miles from the Little Harquahala pumping plant to the Hassayampa pumping plant.

SCADA Training with Hydraulic Simulation

Recently, researchers at the U.S. Arid Land Agricultural Research Center (ALARC) created a training tool that replaces the real canal with a hydraulic simulation model without making any changes to the SCADA software. Employees at WEST Consultants, Inc. recently modified this training tool so that it works with HEC-RAS as the hydraulic simulation model. The training tool is composed of five main components:

1. a SCADA system;
2. a hydraulic model of the canal system and the HEC-RAS computer program;
3. an intermediate software package (SimSuite) which emulates field hardware and maintains physical information such as gate positions, water levels, and turnout flows;
4. an External Data Interface (WEST-EDI) software package which communicates between the hydraulic and intermediate software package; and
5. a proctor software program (SimProctor) used to assist in the training of the Water System Operators.

In a typical set up for Water System Operator training, the SCADA system is installed on one computer (i.e., the Trainee Computer) and the hydraulic model, SimSuite, SimProctor, and WEST-EDI are installed on a second computer (i.e., the Proctor Computer) as shown in Figure 3. The two computers are then connected using a serial cable. Setting the training tool up in this manner isolates the SCADA system from the rest of the training tool. Thus, the Water System Operators will be trained on the SCADA computer and it will look exactly like the SCADA system they will be operating in the future. Water System Operator trainees can be given tasks to route flows through the system or respond to emergencies using the SCADA system on the Trainee Computer. Using the Proctor Computer, the proctor can observe the effectiveness with which the trainees perform the tasks. In addition, the SimProctor program can be used to make unexpected or emergency changes to the system that the trainees must respond to in an effective manner (e.g., change offtake flows, freeze gates, fail pumps). If the trainees do not perform satisfactorily on a given test, the entire system can be reset and the scenario can be repeated until the trainees' performance improves. All of this is accomplished without endangering the real canal system, interrupting customer deliveries, or wasting water.

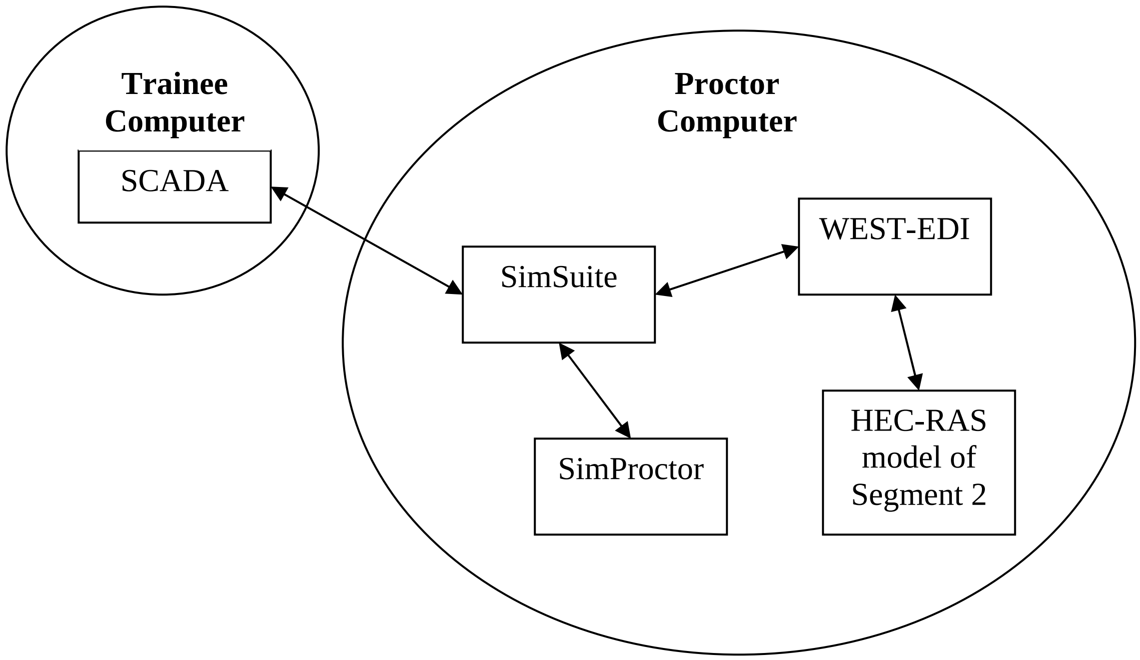

Figure 3. Training Tool Configuration

CAP SCADA System

In this application for CAP, the decision was made to re-create the SCADA screens on a completely separate computer system that was not connected to CAP's local area network or the internet. Since only Segment 2 was being analyzed, the re-development of the SCADA screens was not difficult or time consuming. The SCADA system used for the training tool was iFIX 4.5 by GE Fanuc. SCADA screens were developed for Segment 2 of the CAP canal system. These screens look almost identical to the screens currently used by the CAP operators. Separate SCADA screens were developed for:

1. Check structures 5 through 13
2. Havasu pumping station
3. Little Harquahala pumping station
4. Hassayampa pumping station
5. Vidler turnout
6. Harquahala turnout
7. Tonopah turnout
8. Tonopah Desert Recharge (TDR) turnout
9. Western Maricopa Combine (WMC) turnout

In Segment 2, all check structures consist of two radial gates. Trainees have the ability to change the gate positions for each gate at each check structure. Trainees can also change the flow deliveries at each turnout. In addition, trainees can turn on and off each individual pump at each pumping station. For definition, pump control refers to whether a pump is on or off (as set by the trainees). Pump status refers to whether a pump is nominal (can be turned on or off) or failed. Pump control is set by trainees from the SCADA screens. Pump status is set by the proctor through the SimProctor program.

Hydraulic Simulator and Model

The hydraulic simulator for the SCADA training tool is HEC-RAS, which is an unsteady hydraulic simulator developed by the U.S. Army Corps of Engineers. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. An unsteady HEC-RAS model was created for Segment 2 of the CAP canal and this is probably the most important component of the training tool. If the hydraulic model does not accurately predict water levels for various changes in gate position, turnout flow, or pumping, then the training tool will not be effective because the hydraulic responses that the trainees learn from the training tool will not be the same as those found in the real world. To assure that the hydraulic model was correct, the CAP's custom calibrations for the radial gates were coded into HEC-RAS using the Rules internal boundary conditions. The roughness coefficient for the canal was chosen based on recommendations from CAP personnel. The final hydraulic model for Segment 2 was approximately 62 miles and it consisted of 3 pumping stations, 9 radial gate check structures, 5 turnouts, 3 siphons, and one tunnel.

SimSuite

The SCADA training tool also requires an intermediate software package that emulates the RTU or PLC, its associated sensors and relays, and the gate motor. In the real system, RTUs pass canal information (e.g., gate positions, water levels, etc.) to the SCADA system via some sort of radio system. The RTUs also take commands from the SCADA system (e.g., changes in gate position) and implement those commands in the field. In the training tool, the SimSuite program acts as virtual RTUs that gather information from the HEC-RAS model (e.g., gate positions, water levels, etc.) and pass it to the SCADA system. Likewise, commands from the SCADA system (e.g., changes in gate position) are sent to the virtual RTUs in SimSuite and these commands are then passed on to the HEC-RAS model. Perturbations such as noise, a stuck gate, or a failed pump can be introduced into SimSuite through SimProctor and transmitted to the SCADA system. This software was written by ALARC employees for their applications with other simulation software, and is used unchanged here.

SimProctor

The SimProctor program is used to observe the canal model status from the Proctor Computer. Using this program, the proctor or supervisor can observe:

1) water levels of the various pools in the canal system;
2) gate positions at the various check structures;
3) control of each individual pump;
4) status of each individual pump; and
5) flow rate through each check structure, turnout, and pump station.

The proctor also has the ability to:

1) change the gate positions for each gate;
2) fail any gate;
3) change the flow rate at each turnout;
4) change the control for each pump (i.e., turn the pumps on or off); and
5) change the status of each pump (i.e., change the status from nominal to fail).

Note that there is no indication on the SCADA screens that the gate has failed; the gate simply does not move to the requested position. When a pump fails, it is displayed as orange on the SCADA system.

WEST-EDI

In the application described by Stand et al. (2005), MATLAB was used as the interface from SimSuite to they unsteady flow simulation software. Since a connection between MATLAB and HEC-RAS does not exist, the WEST-External Data Interface (EDI) program was developed to connect HEC-RAS to SimSuite. The function of the WEST-EDI program is to pull information (e.g., water levels, gate positions, etc.) from the HEC-RAS program and then pass it to the SimSuite program. Also, commands from the SCADA system are passed to the WEST-EDI program via SimSuite. These commands are then passed to HEC-RAS. A screen shot of the WEST-EDI program is shown in **Figure 4**.

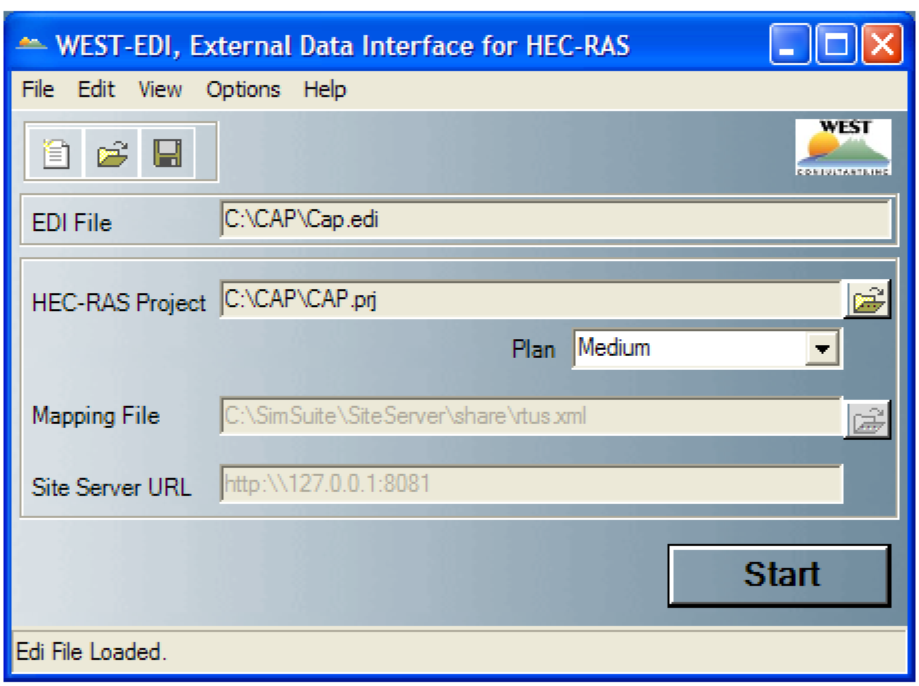

Figure 4. Screen Shot of the WEST-EDI Program

SCENARIO DEVELOPMENT

Three basic flow scenarios were developed along with the training tool for CAP: a high flow condition, a medium flow condition, and a low flow condition. All three of these scenarios start out with the water levels near typical operating levels. Once the training tool has started, trainees must operate the SCADA system to effectively route flow changes through the hydraulic model of Segment 2 while also responding to uncertainties and emergencies that cause the water levels to deviate. The trainees have the ability to move each check structure, adjust the turnout flow deliveries, and turn the individual pumps at the pumping stations on or off. The proctor can observe the trainees' progress by observing their performance on the Proctor Computer. In addition, the proctor can introduce emergency situations by failing gates or pumps. In using these basic scenarios, personnel at CAP have indicated that the hydraulic model is responding to flow changes in a similar manner to the real system. Obviously, the three flow scenarios are not sufficient to effectively train their Water System Operators over a wide range of flow conditions. Thus, CAP is currently in the process of developing a test bank of scenarios that their Water System Operator trainees must pass before they are allowed to operate the canal system independently. This test bank of flow scenarios will cover a wide range of flow conditions, including emergency scenarios.

SUMMARY

A training tool, designed to train new Water System Operators on how to operate the canal system more effectively, was developed for the Central Arizona Project. The main idea behind the training tool concept is that the communication between the SCADA system and the radios in the field is "cut" and replaced with a connection between the SCADA system and a hydraulic model of the canal system. In this way, the Water System Operators can be trained on the hydraulic model of the canal system instead of the real canal.

The training tool is composed of five components installed on two different computers: 1) the SCADA system, 2) the SimSuite program, 3) the SimProctor program, 4) the WEST-EDI program, and 5) the HEC-RAS unsteady hydraulic model and computer program. The Trainee Computer has the SCADA system installed on it. The Proctor Computer has SimSuite, SimProctor, WEST-EDI, HEC-RAS, and the corresponding hydraulic model of the canal system installed on it.

The key component to the training tool is an accurate hydraulic model. A hydraulic model that does not accurately predict water surface changes due to gate movements, turnout flow changes, or pump changes will not effectively train the Water System Operators on the real system. Care was taken in the development of the hydraulic model to assure that the hydraulic modeling accurately predicts the real world. CAP personnel have stated that training tool does respond like the real canal system, indicating that the hydraulic model is adequate.

Currently, CAP is in the process of developing a test bank of scenarios that Water System Operator trainees must pass before they are allowed to operate the canal system independently. This test bank of flow scenarios will cover a wide range of flow conditions, including emergency scenarios. Once trained in this manner, Water System Operators at CAP will have a much broader experience base from which to draw upon while operating the canal system.

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KEEPING IT TOGETHER IN DESTABILIZED TIMES: LOOKING PAST THE NEAR TERM

John D. Wiener[1]

ABSTRACT

This extended abstract proceeds from arguments previously made in the 2008 USCID Urbanization and Irrigation meeting (proceedings; presentation at www.colorado.edu/ibs/eb/wiener/), and elsewhere (posted same place), taking a wider view of the issues facing irrigation in the urbanizing US West. Here, the purpose is to look beyond near-term stresses. Irrigation districts and ditch companies face serious hindrances to long-term planning, including re-allocation to match soils, water, farming abilities, and capitalization as well as the problems of defining the many interests affected by irrigation and acquiring their support in meaningful terms. Certainly, each district and ditch is unique, but some common problems suggest common potentials. Group action created the assets at risk, and group action is needed to sustain them. Given the increasing instability of climate as well as input and output markets within sharply increasing environmental pressures, the importance of agricultural productive capacity calls for careful self-defense. There is little help available, but a rationale for one approach is developed; "Five Capitals".

Looking at the "five kinds of capital" (natural, built, financial, individual and social/organizational) in the future, one may see the need for pro-active assessment of all of the assets of the district or ditch. In 30 years, what would you like to have? What might you grudgingly agree to have in order to stabilize what you want? How can you get that? Irrigation districts, ditch companies and their allies must be the link between land use change and water management, and they may be the leading edge of progress toward sustainability.

EXPLANATION OF PURPOSE AND SCOPE

Extending Previous Arguments

This argument builds on others already made. Here, some of the reasons are reviewed for supporting the approach recommended, instead of something that looks more like science and less like business. Some readers may wish to skip to "the five capitals". This is not about defeating change; the question is how to live through it and with it, which may include some choices that a lot of farmers I know think are just repulsive. The goal is to bring to bear some ideas from work not usually applied in the USCID, to show potential for re-thinking districts and ditches as management of many resources. In 2008, at the US Committee on Irrigation and Drainage meeting in Phoenix, the arguments were made that (1) many of the values created by irrigation in the Western US are being

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systematically overlooked or underappreciated, and (2) that the already serious economic pressures on irrigation are synergistic with additional pressure on water supply, from both changes in supply threatened by climate change, and also changes in demand, particularly from increased urban populations in semi-arid and arid areas (see extended abstract in the proceedings, expanded by the Powerpoint ™ presentation, which has been posted at www.colorado.edu/ibs/eb/wiener/, (" Toward Better Water Transfers In Colorado and Cumulative Cost Avoidance").

Another presentation posted at the same place ("National Security is Dirt…") addresses problems of soil erosion, and suggests that long-term loss of fertility has been masked by increasing substitutes for soil quality. The example used was nitrogen, which is problematic because it is very strongly dependent on fossil natural gas for synthetic forms, and because the US now imports a majority of its use and seems likely to increase the import share (USDA ERS; Schepers and Raun 2008). Pollution problems from excessive N use were also noted (National Research Council 2008). Problems associated with N pollution of groundwater were not mentioned. (See each state's water quality program for formal designation of problems; on responses, see the National Water Program of the USDA Cooperative State Research Education and Extension Services meeting proceedings (http://www.usawaterquality.org/conferences/2008/).)

Soil erosion problems were addressed through the leading work on both the financial and energetic costs and consequences of soil erosion (and other non-point pollution problems from high-input farming) (Pimentel and Pimentel 2008; see "national security is dirt" for additional references). News about price spikes and changes for fertilizers has become all too common; this is another problem for planning on crop choices for the coming year, coupled with commodity markets that seem also increasingly destabilized (USDA Economic Research Service 2008b). Equipment and land prices have also been unusually variable, and one could go on. Business as usual is not all cheerful.

Resilience, Climate Destabilization, and Modeling Severe Uncertainty

Sustainability presumably includes sustaining the irrigators as well as the districts, but conventional high-input agriculture does not seem headed either toward sustainability in any useful sense, nor even toward the older and more easily considered quality of resilience. The idea of resilience – generally, ability to retain capacity to endure and take advantage of opportunities – has been fashionable in regard to natural hazards and climate change, (Intergovernmental Panel on Climate Change, <ipcc.ch>, 2009 and preceding). Regarding US farming, an early and strong case for the concept as a measure and a goal was in Kraenzel, 1955, The Great Plains in Transition. Resilience should not be mistaken for failure to adapt and respond; ignoring the environment – physical, commercial, social – is not sustainable unless there is little change.

Climate science has been clear for decades that things are changing, but the idea of "change" seems to imply a switch to something, when in fact there is no stabilized state of the atmosphere (and therefore hydrology, or the physical environment) in sight (Solomon et al. 2009). There may be no stability or stationarity involved (see Milly et al.

2008, which preceded Solomon et al. 2009). In the long term, things are not clear at all. We are going, with our children and many generations to come, into a different place.

A great deal of current work involves “down-scaling” of products like climate models, to be able to achieve some comforting sense of “precision” about how much warmer nights will be in the corn season in Nebraska in 2050. For leading examples, see the Synthesis and Assessment Products from the Climate Change Science Program (2009), and earlier work in the U.S. Global Change Research Program (same website now: <www.climatescience.gov>). Similarly, there is substantial work on parts of the big picture, such as agricultural output, sometimes using linking of best available models that represent parts of the picture in question. For leading examples, see Rosenberg and Edmonds 2005, and Barnett et al. 2004. The Intergovernmental Panel on Climate Change puts an enormous international effort into developing emission scenarios to serve as the basis for such assessments, and these are available (e.g. Fourth Assessment Report, IPCC 2007). They provide a basis for many other efforts to consider what effects the emissions of gases will have on weather and climate and other outcomes, such as those that follow on in hydrology, the biological impacts, and so forth. We should all be aware of this kind of work and its values and importance.

Unfortunately, getting from that to your district is a long stretch right now – and it may always be a long stretch, in the foreseeable future to address areas on the size scale of irrigation districts or ditches. Then there is the astounding complexity of potential changes in such outcomes as the costs (both financial and otherwise) of imported (meaning also transported) natural gas-based nitrogen where environmental costs may be recognized at some or maybe all stages, where the costs of the fuels are not only the costs of producing them but perhaps a carbon tax or other charge to account for some of the impacts of their use, and so forth. Modeling such linkages even on the large aggregate scale has always been difficult and results have been controversial for scientific and other reasons (Turner 2008).

It gets worse, looking more than a few decades ahead. The entire chain of inputs and outputs can be as complicated as one wishes to make it, and ultimately there is a great paradox. The economically efficient transformation of one resource into another is defined on the distribution of the resources, in terms of scarcity and in terms of who has control of them, and in terms of who bears what costs and who enjoys what benefits. All of the economic valuations are a moving target, and all of the parts seem to be moving faster than usual. Worse yet, the future is not only hard to value in terms of what a thing will be worth in terms of the costs of its production, clean-up, consumption, and so forth, but the math only looks useful. In 500 years, which is pretty trivial in terms of the duration of many of the more unpleasant chemicals we create and carelessly disperse, no matter how nasty the effects, the costs in present dollars look trivial when discounted to present value. In fact, almost everything looks trivial that far out, in discounting (Howarth and Norgaard 1992, and Norgaard 1994, Bromley, Ed., 1995, and see IPCC 1995 for very thorough discussion). Cost-benefit is a clear framework for comparison of complicated choices, and far better than nothing, but it has severe limitations. One classic and depressing example is that economics has little to say about extinction (Clark

1973, 1991), despite the innate human love for the world we live in (Wilson 1984). The most formal and scientific methods are not much help for 5 or 6 generations ahead, or the life of a young redwood or a grandchild black walnut tree. So, it may be good luck that people running a district or a ditch are dealing with a banker, rather than an economist or a climate scientist, since there isn't much help there.

Another Approach from the Literature: Resource Management

The focus of this discussion is the sustainability of irrigation districts, referring to not only irrigation districts organized under the two main Federal laws, but also districts which serve as coordination mechanisms for irrigation as well as being clients of Reclamation projects, and also what Colorado calls "mutual ditch companies", and their parallels in other states. The argument is essentially this: seeking sustainability as only a water distributor is not enough, even if it were likely to work. Cities can simply charge far more for water than farmers can make from it (Woodka 2005; Western Water Policy Review Advisory Commission 1998, National Research Council 1992), so we need a higher marginal value product, to better resist the pressure to sell. Fortunately, we care about far more than the ditches – inside the district, it is the life in farming, the history, and the families, and outside the district, it is the ecosystem services provided, the open space and amenity values of the water distribution, and despite the penny-wise, dollar-foolish "market", the maintenance of high-quality soils and agricultural capacity. No farms, no food. Some of your people want to be able to stay; everyone's great-grandchildren will be very grateful if they can. The goal, then, is making these sets of resources into something that can stand up to the mess we're in.

Districts and ditches have a few things in common. They face the challenges of operating irrigation (however it was established), as a matter of engineering, accounting, and administration. For most, this also includes management to some extent of the internal changes in soils, vegetation, and land use within the district, and all of the consequences of those changes. However created, these are also social entities, which involve coordination of different individual interests, and some public interests, within and outside the district (in this large sense of the term). Dr. David Freeman has said, "Water is the most social molecule…" And, "we get what we organize for." Districts and ditches all face the conditions of external change, from local near neighbors and upstream water users, regional population growth and land use changes, and even the consequences of global change, in markets and values of inputs and outputs, and in the physical conditions of the climate and the effects of those changes on about everything else. What in the library might help?

Much of anthropology, economics and economic geography is concerned with economic development and change. Everyone has heard different explanations for why some places are better supplied with human services, have better local economies, offer more opportunities to residents, and ultimately seem to provide a better quality of life. Explanations range from ideas about character (e.g., work ethic) to geographic location (cross-roads, good farming, raw materials) to history (colonial exploitation) and so forth (Arndt 1987, So 1990, Corbridge 1995). More recently, attention has gone to individual skills and education, summarized as “human capital” (e.g., Ireland’s well-educated population explains economic success), and “social capital”, which is a bit less obvious (discussed a bit below); this refers to informal social networks, as opposed to formal institutions. Different social status, wealth, and individual situations dramatically affect ability to access resources of all sorts, including those provided by groups for themselves or by other organizations, such as levels of government. Community and poverty issues in development are important (Saegert et al. 2001, Cernea Ed. 1991). There is valuable insight from looking at the ditch or district as an object of study that appears all over the world. The most important idea may be that the problems of organizing the people and defending the thing from others are usually much harder than the problem of moving the water around.

FIVE CAPITALS (KINDS OF RESOURCES)

Working toward a practical synthesis, Tony Bebbington proposed “Five Capitals” (1999), to help consider the various resources upon which people can draw in a given place and situation. There are complications in any case, but there are knowable ways in which who gets what and how things can change are organized (see Ostrom et al. 2002, especially, on this point). For our purposes, Bebbington’s cross-cultural approach is modified here; he is not to blame. The five adapted capitals are (1) Natural resources, (2) Built resources – or infrastructure in many cases, (3) Financial resources, (4) Individual human resources, and (5) Social/organizational resources, ranging from informal to governmental resources. These can be called “capital” in the sense of something that can be invested.

An academic note: in respect for the considerable efforts in defining this last category, the essential idea of “social capital” is that informal social networks (who you know and might help you) are a kind of resource that individuals can use, outside of the formally-organized groups, institutions or agencies (Field 2003). The informal networks can be distinguished for research clarity from cultural capital, as a kind of resource of knowledge and traditional obligations (Lin and Erickson 2008) or more general idea of “social structure” (Putnam 2000, Bebbington 1999). Organizational resources are those kinds of assistance to which individuals or other organizations can turn. For instance, there are formal agencies in most state governments to promote economic development (often so-named), which help in various ways (e.g. Nebraska agri-tourism information cited here), as well as less formal groups, such as Chambers of Commerce. For social science, it is important to think very carefully about the different kinds of cultural, social, informal, and formal organizational resources, but for this argument, and some other pragmatic purposes, they can be lumped together, with the warning that how one gets or demands access to the help certainly depends on the source. Another academic note is appropriate: the ability to change one kind of capital into another is a major topic. Less abstractly, it makes a big difference whether you can buy one thing using another, or transform one kind of resource into another. If there is something you need and there is no substitute, you had better find out soon. Presuming that there is “mobility of capital”, as economists say, may mislead one into thinking that one can always convert money into something wanted, although the prices may change; or, to put it another way, you can make a silk purse out of a sow's ear if you spend enough. Unfortunately, this may be false; there is no making another Iowa.

Natural Resources

Within the district, soil quality is probably the least-supported and recognized long-term asset. Rates of soil loss are much higher than rates of soil formation (Pimentel 2008). About 90 percent of US cropland is losing soil at unsustainable rates (see Wiener 2008, for summary presentation). Erosion may be dramatically increased by impacts of climate change such as higher intensity of a larger share of precipitation (Soil and Water Conservation Society 2003), as well as heat-related increases in ET, changes in cultivation related to longer growing seasons favoring weeds as well as crops, and the possibility that some crops are nearing their heat tolerance (Schlenker et al. 2007). The cavalier treatment of topsoil is fostered by the economic valuation problems noted above. We're experiencing increased productivity by using ever-increasing inputs of varying combinations of technology, fossil fuels, and financial support (Ball 2005, Lubowksi 2006, and later USDA ERS information, annually updated). You are invited to consider how the trends in concentration of suppliers of agricultural inputs and buyers of agricultural outputs affect your future. One of the striking problems now is the vulnerability to markets that are beyond farmer control and influence (USDA 2008b). There is a bit of good news, however. One point is that the counter-trend of local food, high quality food, and organic food has been remarkably strong for several decades (Dimitri and Greene 2002, and see USDA ERS "briefing room" on organics. Those practicing diverse farming with ecological resilience and avoiding threats to monoculture and capture by suppliers of seeds, inputs, etc., may have a huge comparative advantage in economic resilience.

Each district should consider the condition and trends of the soil resources, and whether there are mismatches of farming capacity (access to other resources) with the soils, and the will to farm. Are the best soils and water held by those most interested in leaving? How about young farmers? Limits on transferability of water within ditches and districts, and problems with other land uses such as rural residential development can result in messy and inefficient patchworks of land use, with little linkage between resource quality and resource use.

Are your resources good for other crops? The long-term seems to include radical changes in the costs of fossil-fueled transportation, which may mean that the "eat local" trend is strengthened, along with organic and direct sales growth trends. Marginal commodity crop producers may face even worse challenges, along with the pressures from climate change. Rosenberg and Edmonds, 2005, and Barnett et al. 2004 offer dire forecasts for irrigation, based on water supply and demand. The synergy with crop heat tolerances is not clear. If your current crops and rotations lose feasibility, what else could you grow? Again, the best possible soils and resilience seem to be the paramount goals.

What else is in the district? The environmental qualities created by irrigation may have increasingly value, for wetlands banking or credits, and for carbon sequestration plans, particularly if they can be increased, given the prospects for increasing pressure on the water that sustains them. There are also research efforts looking into wetlands and farming as ecologically useful sludge disposal and waste-water management; such programs may have very place-specific conditions, and may eventually involve better control of the miscellaneous “emerging contaminants” in waste-water streams. This is a regional issue as well as a national issue, and one that probably calls for consultation with co-operative extension specialists and other academic resources, and good contracting with an engineering firm and lawyers “on your side” before undertaking unknown risks. These irrigation-supported resources are not “natural” in the sense of pre-development, but what is left of such places is vanishing (Wiener et al. 2008). There may already be serious interest in conserving these resources, and that could be made tangible by deals for easements, and payment to refrain from changing activities that would result in drying up the return flows and conveyance losses that typically support these conditions. Hunters, fishers, and wildlife watchers all benefit from these resources, and many private access deals provide income to land-owners. Group programs could be combined with use of a local government or state program to provide risk management including insurance programs, and also other forms of management, to reduce the hassles for farmers and cope with the exposure to vandalism and other stupidity.

Another kind of resource in the district or ditch is the quality of life from being near water features and their vegetation and wildlife, and the open space and scenery of farming and livestock. The bad news is the risk of people moving in or nearby and deciding your activities are incompatible. But the good news is that “right to farm” ordinances and policies are a popular response. Every state has some sort of farm land preservation program (Hellerstein et al. 2002), though funding was never adequate (see also American Farmland Trust 1997). Some states favor easements; many local governments simply buy farmland to keep it in agriculture as an amenity. But the private sector makes a lot of money from the amenity value of real estate. Water features and open space increase value; see the real estate advertisements in your area. The unfortunate side of this is that isolated rural residential development can have severely adverse tax consequences on local governments (Coupal and Seidl 2003), and severe ecological consequences (Theobald 2003, Theobald et al. 2005). So far, the author has not found useful research on septic system and individual water supply problems, though agricultural impacts on water quality are a major topic. Meanwhile, ditches surrounded by development are treasured assets in the West – they are the source of trees and wildlife in places where the short-grass would otherwise be the only thing in sight more than a few yards away from the flood area of a natural watercourse (Wiener et al. 2008).

How to make use of the amenity value for the benefit of more than the seller of the land and so as to avoid adverse impacts for others is the big question. Suppose you had to locate a dozen “ranchettes” in your territory? Suppose you were thinking seriously about the long term and trends in the market and decided to look more broadly: where would you put in a higher-density planned unit development, to create value for the buyers and yourselves, and defend the agricultural capacity of the rest of the land? Suppose you included some commercial space, some public facilities, and things that your people may already badly want, such as decent retirement living in the area they live in? Some farmers leave, but many who “sell out” stay in town (Weber 1992).

If you were a big-money real estate developer, what would you do? You would certainly not pull random plots out, here and there, and you would not put a single ranchette on the only part with a good view, if you could sell 30 condominia and some lucrative retail and services facilities, on the same land for a whole lot more money… And you would be thinking about preserving the farm option, defending the best soils and the best water access… You get the picture. One more note on this: you would have landscape architects and design resources as well as marketing specialists. If you don’t, however, you could look into consulting with some to see what would be involved in getting real help on thinking about the land resources and what kind of costs and benefits might be involved in trying to develop part of the land in order to support the rest. More on that below.

Outside the district, there are plenty of negative factors – increasing population, water demands, water pollution, and even air quality problems, as well as losing the agricultural character of many communities. Hydrologic impacts from outside development may be severe, such as increased storm-water run-off with “flashier” characteristics; this can be disastrous for a ditch not properly defended throughout the planning and development process “upstream”. How to get advantage from any of that? One important asset is the continuity of the water features – the value of greenways and riparian corridors for both environmental and amenity/recreation interests may be multiplied with larger areas, in regional conservation and operations planning. Despite ritualistic denouncements of “them”, environment-minded people (who are your local customers, also) may be your best allies in getting political and financial support for conservation programs, and “smart growth” that conserves energy and other resources (see US EPA 2009).

Another important asset is the whole set of outsiders who want to be near open space and farming. They want you to stay and they may be willing to push their local governments to support that, with farm-friendly policies and perhaps investment in easements or other deals to put money where the interests are. And, there are people with recreational interests, notably horses and small stock, who should be your customers for feed and care, and might pay for access to trails and other facilities in the district (and their management so as to not injure farming). The “agri-tourism” movement (Nebraska, cited below) shows the love people have for some kinds of farming; notably, this does not seem to apply to concentrated animal factory operations.

Built Resources

The district (ditch company, etc) has a set of resources which may be hard to value. The replacement cost for water conveyances can be estimated, at any given time, but the rights of way may be surprising. In Colorado, water conveyance has a prescriptive easement across the lands it traverses, but these were often unrecorded and many have become problematic. The Ditch and Reservoir Company Alliance has addressed this in several educational efforts, including the Ditch and Reservoir Company Handbook publication. Unfortunately, there is also a body of case law in which these rights have been enforced with unfortunate expense and delay (Corbridge and Rice 1999). The right of way may have substantial value for compatible uses, and some creativity and risk management has led to very productive novelties. The USCID meeting in Phoenix in May 2008 featured a tour of recreational and development deals made to maximize the value of water conveyances in the urban setting. In peri-urban or suburban settings, there may be opportunities for utility location as well as carriage for other water. The FRICO (Farmers' Reservoir and Irrigating Company) has been surrounded by metropolitan sprawl, north and west of Denver, but the farmers left have not paid a nickel in assessments for many years, as the company has received tens of millions of dollars for conveyance of water and other uses of their rights-of-way and structures which are compatible with farming, and the company is remarkably strong (DiNatale 2009). The problem of storm-water drainage must be addressed as a threat, especially where new development is carelessly designed, but there may be opportunities for revenue and benefits from undertaking services that are needed by others. These are likely to be very place-specific, of course, but the seasonality of some kinds of needs may be helpful. Summer thunderstorm run-off may be different in water quality from spring snowmelt, and of course, the interests of the district may or may not be reflected in land use management in relevant areas. Early and persistent assertion of ditch needs and interests may help establish benefits and avoid costs. Many of the problems are addressed in similar situations, such as the wide-spread conversion of abandoned rail lines to trails (See Rails to Trails Conservancy for information). Denver's most popular park may be the Highline Canal, used for amenity and recreational values, and designated a National Landmark Trail (http://www.denverwater.org/recreation/highline.html>.

The other built resources of the district may include water storage facilities, which are a perennial problem and opportunity. Recreational and environmental interests may be allies if careful risk management is undertaken, and there might be substantial popular support for taking advantage of the amenity value of the reservoirs and ditches with adequate management. This is not a novelty; of course. Boating leases are fairly common. The open question here is whether you are better off with no access, non-motorized and perhaps otherwise limited access, or the state parks motor-boat, boat ramps, oil slicks, and all that kind of lease.

Financial Resources

The district typically may be serving a very narrow range of functions, but as this and other conferences have shown, the expansion of roles and services is widespread. This carries with it the expansion of financial activity as well as administration. The financial capital, however, may be limited to reserves developed for paying off debt, or accumulated for replacement costs. Should that be the case for your district? It may be critical to accumulate financial ability to make changes and respond to opportunities. This would follow from the decision to use a district for more than irrigation, and that in turn opens the question of whether the district as presently constituted is a suitable entity for new purposes.

The key to a major asset management program may be establishment of an overlaying district which serves the many purposes not within the scope of permitted activity for some statutory districts. The legal mechanics are probably easier to work out than the fundamental questions of what you want to do. So, this is not a logically prior question. Meanwhile, the financial resources available to the irrigation district are probably minimal, because of the narrow purposes traditionally undertaken. But the irrigators are often land-owners, and their whole set of assets calls for care and use to help meet their goals, not just meeting the next note.

One trend with many names and terms is water sharing, as a lease, long-term lease, rotational fallow program, interruptible supply contract, or water banking operation (Clifford et al. 2004 is one survey; for references to Colorado statutes, see materials posted at <www.colorado.edu/ibs/eb/wiener/>, including progress reports. Behind all the terms and legal issues, the essential feature is shared ownership, which is different from traditional one-owner deals in important ways. First, the security of interests held by both parties is protected. Now, cities buy water rights and if the liquid is not needed, lease it back to farmers (or other cities, sometimes). The farmers who sold are not going to be able finance much on the strength of getting water maybe, sometimes, for a while. Second, the new deals are likely to be fairly complicated, with a lot of contingencies and schedules of payments to cover costs. Third, urban supply from shared water deals is likely to involve several different kinds of contracts or transfers, since urban demands are variable, though in ways that differ from agricultural demands, and so are supplies.

Most important, long-term deals, “permanent” or not, can provide, in the author’s opinion, a kind of financial security that has never been available to farming before. The deal is that you get the water or the money, perhaps with some money every year no matter what, and perhaps with different amounts depending on timing of decisions, and what costs have been incurred, and perhaps even what profits are foregone. Imagine planning facilities and investments with the long term in sight, not the year or maybe three to five years to pay-off. Similarly, imagine being able to make changes incrementally, and experimentally, knowing that you can afford different kinds of risks and trials (for some details, see website above).

Individual Resources

Here, there is likely to be considerable untapped depth. Almost everyone irrigating for more than a hobby has a working knowledge of a great many kinds of hardware and design, and the skill to operate and repair a lot of equipment. The practical meaning for new purposes is that the need for new tools may be minimal, and the knowledge to be an informed purchaser of services and work is likely to be in the group. But, are you in a group, or just paying assessments like a water bill?

The less-appreciated knowledge accumulated over years of attention to a place may be a huge asset to rethinking and redeveloping. This ranges from knowing the soils and drainage characteristics of fields and farms, to knowing the local topography and environment around the farms and district. In foreign countries, this might be

"Traditional ecological knowledge" or "local knowledge", and it may be the key to the best design for new mixed uses of the whole set of assets available. What fields ought to be the first to go out of production? Where should new residential units be located, to minimize the loss of production? Where should new buildings and activities best be located to reduce interference to and from ongoing farming?

The horse and animal skills farmers have may also be valuable resources for recreational uses. Horses are so important to so many people, and there is so much money involved in their care, feeding, training, and use, that horse-oriented controlled and planned development may be the first thing to consider for many districts. Offering the needed services as well as the needed place may be commercially quite effective, especially for urban people who want a second residence which includes horses and might not include all the responsibility for care. With fuel prices likely to increase, long commutes would seem less and less desirable, so there may be a huge market for making the country place with the ornamental hay burner still possible, by providing stables and management in a fashion that profits the district and perhaps its young people as well. Why should real estate developers make all the profits from development?

Social and Organizational Resources

This is a fuzzy and complicated topic, ranging from cultural traditions as a kind of resource, (the basis for acequia management, Amish barn-raising, and those long hours of 4-H work) to more concrete and visible organizational resources. All of the organizations on which a person or group can call may be considered a resources, and the district itself has a history of being a resource. What kinds of help are available? What organizations – from state and federal government agencies, to local groups – have some interest in your operations and continued viability? What can they do to hurt, hinder, or help you?

In the fairly obvious category, there is the range of assistance programs such as those administered by the USDA Farm Service Agency and Natural Resources Conservation Service, which are often narrowly targeted toward particular goals. Reduction of adverse environmental impacts or provision of benefits (EQIP, WHIP, etc programs) may be completely compatible with the goals of the district.

Less obviously, there may be programs that can help with design and investigation of alternatives and choices; these may be intended to work with local governments, such as the National Park Service's Rivers and Trails Conservation Assistance program. Local governments noted above in connection with outsider interests in the good things that districts and ditches provide may be able to offer considerable assistance in working on what is possible, and how to increase value for all by linking and cooperation.

The real missing link is deliberate creation of social resources – through organizing yourselves for your own purposes. One of the clever ways to share costs and benefits from working together is use of transferable development rights, through a special district or a set of inter-locking covenants. Instead of farms being picked off piecemeal, often secretly (Olinger and Plunkett 2005), a ditch or district can organize to do together what individuals cannot do. The essential purpose is to create value – all the land is more valuable when the residential property has security of value because the neighborhood won't lose what the buyer wants, and the farm ground won't be encroached on, or surrounded by sprawl or creeping development. Planning has been made a dirty word in a lot of reckless pandering to people's frustrations, but it is the explanation for about everything that makes cities, towns and countries work, and it is the lifeblood of infrastructure. It is how we work together.

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RECOVERING FROM DISASTERS, LESSONS FOR IRRIGATION DISTRICTS

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ABSTRACT

Irrigation districts and other water supply agencies frequently experience damage from natural disasters, including floods, fires, earthquakes, and hurricanes. The Federal Emergency Management Agency (FEMA) provides grants to make repairs to damaged facilities and to cover other disaster-related expenses through its Public Assistance Program. Federal grants can cover 75% or more of the costs of repairs and other expenses, and many states provide additional grants so that the local agency only has to pay a small portion of the recovery costs.

While performing repairs and other emergency work, it is important that the local agency keep accurate and detailed records of costs, and follow reasonable practices in hiring contractors. FEMA can also provide grant funding for system improvements to prevent or minimize future disaster damage; however it is important that improvements are not made prior to FEMA approval and environmental compliance.

During the past 15 years, the author has had several assignments as a FEMA Disaster Assistance Employee (DAE) and a Technical Assistance Contractor (TAC) employee. The paper will cover several of the author's experiences documenting damage and writing reports to justify FEMA grants for water districts and other local agencies. The paper will also discuss how FEMA obtains staffing for disaster recovery, and the resulting opportunities for engineers and other water experts for part-time work.

INTRODUCTION

Irrigation districts and other water supply agencies frequently experience damage from natural disasters, including floods, fires, earthquakes, and hurricanes. The Federal Emergency Management Agency (FEMA) provides grants to make repairs to damaged facilities and to cover other disaster-related expenses through its Public Assistance Program. Federal grants can cover 75% or more of the costs of repairs and other expenses, and many states provide additional grants so that the local agency only has to pay a small portion of the recovery costs.

This paper will give examples of several recent disasters that have affected irrigation districts, define Federal Emergency Declarations and Major Disaster Declarations, list the various categories of damages and expenses that are eligible for Federal relief, describe hazard mitigation measures that can be funded, and list actions that should be taken by irrigation and other water districts when disaster strikes. The paper will also discuss how FEMA obtains staffing for disaster recovery, and the resulting opportunities for engineers and other water experts for part-time work.

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DISASTERS AFFECTING IRRIGATION AND WATER DISTRICTS

Over the past several years there have been numerous instances where irrigation and other water districts have been impacted by disasters that have been declared Federal Disasters by the President. Some that come to mind are:

1. 1995 floods in California. The Placer County Water Agency suffered damage to its water conveyance system. The South Tahoe Public Utilities District suffered damage to its pumping plant which transport treated waste water out of the Lake Tahoe basin and to its irrigation distribution system where the waste water is reused.
2. 1996-1997 floods in California. The El Dorado Irrigation District’s main canal was destroyed by mud slides in a remote area, and access for repairs had to be made by helicopter. A main conveyance canal of the Georgetown Divide Public Utility District was washed out and a portion was replaced by a pipeline. The Don Pedro Reservoir of the Turlock and Modesto Irrigation District filled for the first time and flood flows over an emergency spillway damaged a road and other facilities.
3. 1998 Typhoon Paka in Guam. Typhoon force winds and flying debris severely damaged telemetry stations of the Guam Water Authority.
4. 1999 Hurricanes in Florida. The South Florida Water Management Agency suffered damage to many of its flood control and water conveyance facilities.
5. 2004 Hurricane Ivan in Alabama. The City of Pine Hill’s waste water reuse irrigation system was damaged by trees which were uprooted by hurricane force winds. The City was without power for a week, and had to rent a generator to power its water treatment plant.
6. 2004 Hurricane Charlie in Florida. The City of Fort Myers experienced severe damage to its domestic water and waste water treatment plants, pumping plants, and conveyance systems.
7. 2005-2006 Floods in California. The Nevada Irrigation District experienced damage to its water conveyance system. Flows to The City of Nevada City’s waste water treatment plant more than tripled due to runoff and infiltration to its collection system, requiring the City to staff the plant around the clock, resulting in many hours of paid overtime.
8. 2008 Flood in Nevada. A major canal of the Truckee-Carson Irrigation District breached, causing not only damage to District facilities, but much more extensive damage in the area of Fernley, Nevada.

FEDERAL DISASTER DESIGNATION

The Federal government can declare two types of disaster relief: Emergency Declarations and Major Disaster Declarations. An Emergency Declaration can be declared when the President determines that Federal assistance is needed to supplement State and local efforts to provide emergency services, including protection of lives, property, public health, and safety, or to avoid a catastrophe. In 2008 there were 68 Emergency Declarations, of which 51 were fire emergencies.

A Major Disaster Declaration can be made by the President for any natural event; including any hurricane, tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought, or regardless of cause, fire, flood, or explosion. In these cases, the President must determine that damage is of such severity that it is beyond the combined capabilities of State and local governments to respond. The declaration of a major disaster provides a wide range of Federal assistance for individuals (Individual Assistance or IA) and public infrastructure (Public Assistance PA). Funds are available for both emergency and permanent work. This paper will include a discussion of only Public Assistance. In 2008 there were 75 Major Disaster Declarations.

In many cases an Emergency Declaration is first made, and then as it becomes apparent that the damage is severe, a Major Disaster Declaration is made. For example, Hurricane Ike in September 2008 resulted in Emergency Declarations in Texas, Louisiana, and Florida, followed by Major Disaster Declarations in Texas and Louisiana, but not in Florida. In November 2008 three Fire Emergencies were declared in California, followed by one Major Disaster Declaration which covered damage caused by all three fires.

Both Emergency Declarations and Major Disaster Declarations can be made in any part of the United States, including commonwealths and territories, and are made on a state-by-state basis. For example, Hurricane Ivan in 2004 resulted in 9 disaster declarations in as many states.

As of mid-April there had been 19 Major Disaster Declarations and 5 Emergency Declarations made in 2009. Emergency Declaration 3300 was made on January 13, 2009 to assist local agencies in managing the 56^{th} Presidential Inauguration.

CATEGORIES OF DAMAGE AND EXPENSES

Disaster related work has been divided into seven categories by FEMA; two categories of emergency work (A and B) and five categories (C through G) of permanent work. It is possible for irrigation districts and other water agencies to experience disaster related expenses in all categories.

Category A: Debris Removal

Debris removal includes clearance of trees, building wreckage, sand, mud, silt, gravel, vehicles, etc. Debris can be caused by most types of disasters, but is most prevalent following hurricanes or tornados.

Category B: Emergency Protective Measures

These are measures that are taken before, during and after a disaster to save lives, protect public health and safety, and protect improved public and private property. Any public agency can take these measures; those most typically involved include police, fire, sheriff, and state and local emergency management agencies.

Category C: Roads and Bridges

Category C includes the repair of roads, bridges, shoulders, ditches, culverts, lighting, and signs.

Category D: Water Control Facilities

Repair of water control facilities includes irrigation systems, drainage channels, and pumping systems.

Category E: Buildings and Equipment

This category includes the repair of buildings, office equipment and systems, heavy equipment, and vehicles.

Category F: Utilities

The utilities category includes the repair or replacement of water treatment and delivery systems, power generation facilities and distribution lines, and sewage collection and treatment facilities.

Category G: Parks, Recreational Facilities, and Other Items

This category includes repair and restoration of parks, playgrounds, pools, cemeteries, and beaches.

ACTIONS TO TAKE

Application for Disaster Assistance

Eligible Applicants include state government agencies and local governments including counties, cities, school districts, water districts, and irrigation districts. Private nonprofit organizations or institutions that own or operate facilities that are open to the general public are also eligible. Such nonprofit organizations include emergency, educational, medical, and custodial care facilities. Federally recognized Indian Tribes are also eligible.

When a disaster has occurred in your area, you will probably be aware through personal experience and the local media. The FEMA web site (**www.fema.gov/**) will also have up-to-date information on Federal Declarations. Once a Major Disaster Declaration has been made, a representative from the state will conduct an Applicants' Briefing for all potential applicants for public assistance grants. These briefings are typically held on a county-by-county basis, on with a few counties. Often the counties' emergency management agency will also be involved. Application procedures, administrative requirements, funding, and eligibility criteria are covered at the meeting. FEMA personnel will cover issues of eligibility of work, floodplain management, insurance requirements, environmental and historic preservation considerations, Federal procurement standards, and mitigation requirements.

If possible, each applicant should send three representatives to the Applicant's Briefing: an elected or appointed official, a representative from the accounting department, and a representative of the construction, maintenance, or operations department.

Each applicant must then complete an Application for Public Assistance. The Federal Grant will cover at least 75% of the eligible cost or the disaster-related expenses. Many states provide additional grants so that the local agency only has to pay a small portion of the recovery costs. For example, California contributes 12 ½ % of the cost, leaving the local entity with only 12 ½ % of the cost. In some cases, the Federal Government has contributed up to 95% of the cost of disaster recovery.

Federal grant funding is available for all disaster related work and expenses with one exception. For emergency work (Categories A and B), work by your own staff (force account) is funded only for overtime work. The rationale is that work conducted during the regular work schedule is not an added expense for the agency. All other expenses, including overtime labor, equipment use and rental, supplies, material, and contract work is eligible for grant funding.

Records to Keep

It is very important to keep detailed and accurate records of damage and disaster related expenses, especially for work completed or underway before FEMA personnel (usually known as a Project Officer or PO) visit the local agency. Pictures and measurements of the extent of damage are especially helpful. Records of manpower and equipment hours and receipts for purchase of material and supplies are necessary for each damaged facility and for each category of work. This should be easy to do if your agency has a work order system to keep track of individual jobs. If the work has not started or completed by the time of the FEMA visit, the Project Officer will collect or assist with obtaining field data and will recommend on the records to keep.

Contracting Practices

Reasonable construction practices must be followed. Costs must be reasonable, and contracts generally must be competitively bid, and must comply with Federal, State, and local procurement standards. Four methods of procurement are acceptable to FEMA.

Small Purchase Procedures This is an informal method for securing services or supplies by obtaining several price quotes form different sources and do not cost more than $100,000.

Sealed Bids This is a formal method where bids are publically advertised and solicited, and the contract is awarded to the responsive bidder whose proposal is the lowest in price. In general, this method for procuring construction is preferred by FEMA.

Competitive Proposals This method is similar to sealed bid procurement in which contracts are awarded on the basis of contractor qualifications instead of on price. This method is used for procuring architectural or engineering professional services.

Non-Competitive Proposals This is a method whereby a proposal is received from only one source. This situation could occur when the item is available only form a single source, there is an emergency requirement that will not permit delay, or the competition is not adequate to seek additional sources.

Reimbursements for three types of contracts are acceptable.

Lump Sum This is a contract for work within a prescribed boundary with a clearly defined scope and a total price.

Unit Price This is a contract for work done on an item-by-item basis with cost determined per unit.

Cost Plus Fixed Fee This is either a lump sum or unit price contract with a fixed contractor fee added to the price. Cost plus a percentage fee contracts are not acceptable.

In summary, the contracting procedures you should follow are the same as you should follow if the agency were bearing the entire cost.

The Project Worksheet

The report that documents the disaster related expenses and damage is called the Project Worksheet (PW). In general, a separate PW written for each category and for each damaged facility. To be eligible for FEMA grant funding, a minimum of $1,000 in expenses in a category is required. PWs that have costs less than $60,400 are called Small Projects; PWs above that amount are called Large Projects.

Who Writes the Project Worksheet Usually the FEMA Project Officer writes the PW; however the local agency has the option of writing its own PWs, and having them reviewed and approved by FEMA. Few local agencies write their own PWs, as it takes quite a bit of review of regulations, procedures, and research to write the PWs. Unless writing your own PWs will significantly speed-up the process of writing, review, approval and funding, there is no advantage to writing your own PWs.

Cost Estimates for the Project Worksheet For work that is already completed, actual costs are used. Contract bid amounts are also used. For work that is not yet started or completed or not yet bid, unit costs are usually used for estimates. FEMA has unit cost estimates for each state, which are used unless local unit costs are available and can be verified.

Grants for completed projects are made based on the actual costs documented in the PW. Grants for Small Projects not yet completed are made based on the PW estimated cost. If the net actual cost for all Small Projects for an applicant exceeds the net estimated cost for all Small Project PWs, the local agency may request supplemental funding for a net cost overrun. For Large Projects not yet completed, estimated costs are used for the PW, and are revised to the actual costs once the project is completed.

Disaster Related Expenses and Damage Occasionally, a local agency will try to include repairs to facilities for non-disaster related damage. It is important to include only disaster-related damage and expenses in your request for FEMA grant funding.

Hazard Mitigation Proposals

Hazard mitigation funding is available for cost-effective measures that would reduce or eliminate the threat of future damage to facilities damaged during a disaster. For example, replacing an unlined ditch which was washed out by a flood with a lined canal or a pipeline would be considered as a hazard mitigation project if it would provide improved protection from a future flood. Since such a proposal would be different from replacing the unlined ditch in-kind, environmental compliance must be completed before the project can be initiated.

OPPORTUNITIES FOR WORK

When a Major Disaster Declaration is made, FEMA will establish a Disaster Field Office (DFO), usually in the State capital or in a major city in the area of the disaster. FEMA utilizes several resources to staff DFOs, as shown in Table 1. At the onset, most of the

Table 1. Staffing for Disaster Recovery

Staffing for Disaster Recovery
Full Time FEMA Employees
Disaster Assistance Employees (DAE)
Other Federal Agencies
Bureau of Reclamation
Corps of Engineers
Forest Service
Contractor Employees (TAC)

staff is made up of full-time career FEMA employees. As the DFO grows in size several other resources are used. Disaster Assistance Employees (DAEs) are part-time employees that FEMA has on-call. Many DAEs are retirees from Federal and State agencies that are involved in public works projects. Other DAEs are younger people who enjoy the opportunity to work part-time and to travel to far-away work sites. In this case, "part-time" work is defined as part of the year, as work schedules on disasters can be 60 to 80 hours per week.

For major disasters, other Federal Agencies, including the Bureau of Reclamation, Corps of Engineers, and Forest Service, are called on to send a contingent of employees for periods of up to several months. Finally, FEMA has several indefinite quantities contracts with large firms to provide additional staffing on short notice. These contracts usually last for five years and are called Technical Assistance Contracts (TAC). While these firms first utilize their regular employees, they also hire part-timers to fill FEMA's staffing needs.

Disaster-related work, either as a DAE or as a TAC employee, provides excellent opportunities for part-time work for retired Federal, State, or local agency employees. Backgrounds in civil engineering, construction, maintenance, cost-estimating, accounting, emergency services, and insurance are especially needed.

CONCLUSION

Disasters can occur at any time. By being prepared and by having a general knowledge of the FEMA requirements and procedures for disaster recovery, you can ensure than most of your disaster related expenses can be reimbursed and you can proceed with needed repairs. Part-time job opportunities are also available for interested individuals with irrigation and water resources experience.

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CANAL SEEPAGE REDUCTION BY SOIL COMPACTION

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Monte Soto[2]

ABSTRACT

Canal lining for seepage reduction is extremely expensive. Compaction of soils during the construction of earthen dams is essential for seepage reduction. In an effort to determine if simple in-situ vibratory soil compaction could minimize seepage losses, ITRC conducted large-scale tests on the sides and bottoms of five irrigation district earthen canal. When the sides and bottoms were compacted, reductions of about 86% were obtained; reductions of 12 – 31% were obtained when only sides were compacted.

INTRODUCTION

Irrigation districts that rely upon long, open canals share a common problem: canal seepage. Canal seepage can create difficulties including:

- Reduced water deliveries to farmers
- Increased pumping costs if the water in the canals is lifted by pumps
- Increased drainage problems, possibly causing crop yield and health problems
- Loss of water supply in a basin if the seepage goes to a salty aquifer or into the ocean
- Increased diversion from rivers, resulting in decreased in-stream flows

The two most common solutions for reducing seepage are lining canals or replacing them with pipes. These options bring along with them additional benefits, such as stabilization of banks (with canal lining) or reduced need for access and fewer drownings (with pipelines). However, these solutions are expensive. A typical piping cost in California for an irrigation district is in the neighborhood of $120-$300/foot for pipe sizes in the 4 feet to 5 feet diameter range (flows in the 20–30 cubic feet per second [CFS] range). Canal lining costs are often in the neighborhood of $1 million per mile, which is prohibitive for most irrigation districts. A medium-sized district may have more than 100 miles of unlined canals.

The general concepts of soil compaction for seepage reduction and soil consolidation are well documented in civil engineering, under the category of "soil mechanics". Everyone is familiar with compaction of soils for roadways, even if they do not understand the technical details. New canal bases are often compacted using standard engineering techniques. But most canals were crudely built, and we have never seen any attempts in the US to reduce seepage by running compaction equipment over the canal surfaces (without doing the standard over-excavation of soil and careful compaction of replaced soil in layers). Therefore, the Irrigation Training and Research Center (ITRC), with support from CALFED and the California Agricultural Research Initiative, conducted

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some research to evaluate the effectiveness of in-place compaction of canal banks and canal bottoms in reducing canal seepage.

Concepts of Soil Compaction

First, two of the major dams in California (Oroville Dam and San Luis Dam) are earth-filled dams rather than concrete structures. Obviously, proper soil compaction can reduce seepage.

Soil laboratory tests for compaction (Proctor and Modified Proctor) have specified procedures by ASTM. Samples of soil are compacted in specified layer thicknesses, with specified weights dropped a specified number of times from a specified height. In a compaction test, this is typically done with a number of samples, each having a different soil moisture content. A graph such as Figure 1 is developed, illustrating what the moisture content should be during construction. The purpose of this compaction is generally to build a solid soil foundation that will not settle over time, or which will not deflect when subjected to transient loads. Seepage reduction is not a typical goal except for dams.

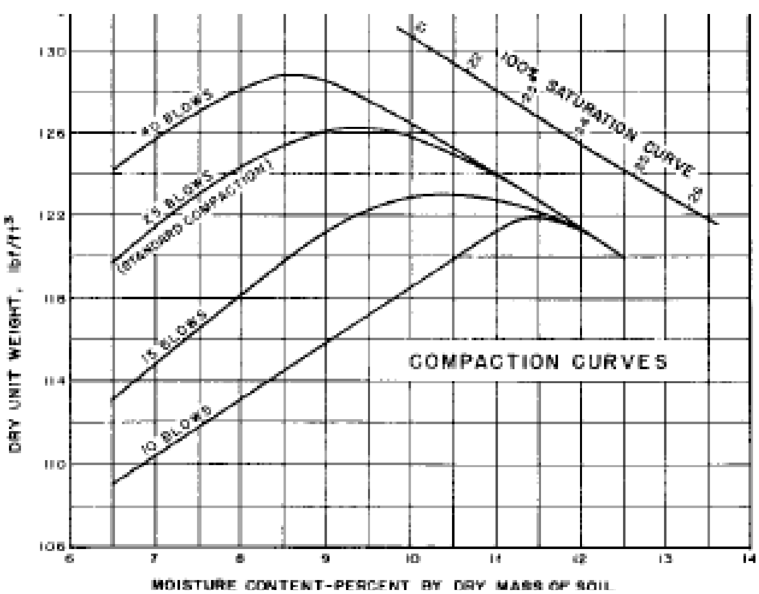

Figure 1. Compaction curves (USBR, 1998)

Some soils compact better than others and as the level of compaction increases, the soil hydraulic conductivity (seepage rate) decreases. Optimum compaction for a high bulk density will also depend upon the moisture content during compaction (see Figure 1). If the soil is too moist or too dry, it will not achieve the “optimum bulk density”.

The details of compaction are more complex than indicated by Figure 1 alone. The optimum moisture content is not only dependent on soil type/gradation; it also depends upon the amount of energy applied to the soil for compaction purposes. Therefore, different laboratory compaction test procedures yield different results. The Standard Proctor Optimum Moisture Content (SPOM) varies considerably from the Modified

Proctor Optimum Moisture Content for the same soil. Further, energy levels (hammer mass, drop height, and number of drops) applied in determining SPOM and MPOM are arbitrary in nature. The Standard Proctor test was developed in the 1920s when static rollers were state-of-the-art. The Modified Proctor test was developed in the 1950s and reflected the increased compaction capabilities of vibratory compactors. Today, technology has advanced even further in terms of energy applied by at least a few compactors, including vibration speeds, pressure, and configuration of the pads/rollers. In general, the higher the applied energy, the lower optimum moisture content will be.

The optimum moisture content for high bulk density cannot necessarily be converted into the optimum moisture content for reduced seepage. Some engineers believe that a slightly-moister-than-"optimum" soil in the field provides the best seepage reduction for non-clay soils.

There are challenges here for in-situ compaction for seepage reduction.

1. Normally one only has a small window of time during which the canals are "dry". Because clay soils can liquefy during compaction if they are too wet, clay soils should probably be compacted at moisture contents slightly below the "optimum" moisture content – if the objective is seepage reduction. It is extremely difficult to dry a clay soil to below the "optimum" moisture range. Therefore, it is extremely difficult to properly compact clay soils. On the plus side, usually the clay soils have low seepage rates. On the negative side, what small amounts of water do seep out often show up on the surface of the soil next to the canal and create operational headaches for farmers and district personnel.
2. If one applies a laboratory compaction test (at various moisture contents) to a soil, it is fairly easy to determine differences in bulk density, as illustrated in Figure 1. It is entirely different in determining the effect on hydraulic conductivity. Over a wide range of compaction conditions, the laboratory tests will yield very similar results – a drastic reduction of hydraulic conductivity. To look at the lab results, one could conclude that as long as there is some compaction the seepage would almost be eliminated. It doesn't turn out quite that good in the field.
3. A canal is removed from service for a few weeks, perhaps, prior to compaction. That means at each depth from the surface, there is a different moisture content.

Table 1 indicates that the best type of compaction equipment will vary, depending upon the soil type.

Table 1. Compaction equipment (Bader, 2001)

Effect of Soil Type on Equipment selection				
		Vibrating Sheepsfoot Rammer	**Static Sheepsfoot Smooth Roller**	**Vibrating Plate Vibrating Roller**
	Lift Thickness	*Impact*	*Pressure*	*Vibration*
Gravel	12 in.	Poor	No	Good
Sand	10 in.	Poor	No	Excellent
Silt	6 in.	Good	Good	Poor
Clay	6 in.	Excellent	Very Good	No

Table 1 does not cover all possible choices of equipment. For the compaction research, ITRC purchased a Universal Vibratory Wheel (UVW) Roller from MBW, Inc. This is a sheepsfoot in-drum configuration. The operator can select the mode of vibration for a particular condition. It can be operated in static mode (clays), vibratory mode (little host machine down pressure, for sands and gravels), and in a mode that combines variable host machine down pressure to a maximum of roughly 30,000 lbs. (at the end of an excavator arm) with full vibration (clays, mixed soils, most native soils).

Soil Compaction for Sealing Canals

Perhaps the best source for information on earth lining of canals is a publication by ANCID (Australian National Committee on Irrigation and Drainage, 2001) entitled "Open Channel Seepage and Control". This publication, as well as others, focuses on bringing soil material to the site one layer at a time and properly compacting each layer. The publication does mention "in situ" compaction – which is in-place compaction of existing canal banks and bottoms. The senior author has talked to engineers from dozens of irrigation districts in California about this, and has not encountered anyone who has tried in-situ compaction before this research – which seems difficult to believe but seems to be the case.

FIELD EXPERIMENTS IN CALIFORNIA

ITRC contacted four irrigation districts in the San Joaquin Valley of California which were experiencing seepage problems:

- Panoche WD
- Chowchilla WD
- San Luis Canal Co. (also known as Henry Miller Reclamation District)
- James ID

Seepage tests were conducted on two Panoche WD canals, and it was determined that the seepage rates were very low. Plus, the soil was a heavy silty clay loam and it was impossible to dry the soil out enough for compaction without just making mud.

The other three districts had sandier soil, so compaction trials were conducted there. The results of one canal compaction effort in Chowchilla cannot be reported because the well that would have supplied the water for post-compaction seepage tests failed and was not repaired.

All the compaction work was "in-situ", meaning that there was no addition of soil, and no over-excavation and replacement of compacted soil layers. The compaction was performed on the soil surface "as-is" with the exception of some smoothing of canal banks.

Seepage Tests. Prior to and after compaction, ponding tests were conducted to determine the seepage rates. The ponding tests involved the following:

- The entire canal pool that was compacted was filled with water to the normal operating depth.
- The ends of the pool were sealed to prevent water from entering or leaving the pool.
- Weather data was recorded from the nearest CIMIS station, to estimate evaporation losses.
- Redundant water level sensors were installed to measure the change in water depth versus time.
- The water was replenished occasionally with a metered supply to maintain a fairly constant water level.
- Water temperatures were measured, to correct for different viscosities in pre- and post-compaction tests.
- Measurements began after water had been standing in the pool for several days, and continued for 1-3 days.

Figure 2. James ID Main Canal during pre-compaction seepage test

Figure 3. James ID Main Canal during side compaction

Figure 4. Ride-on vibratory compactor for bottom of canals.

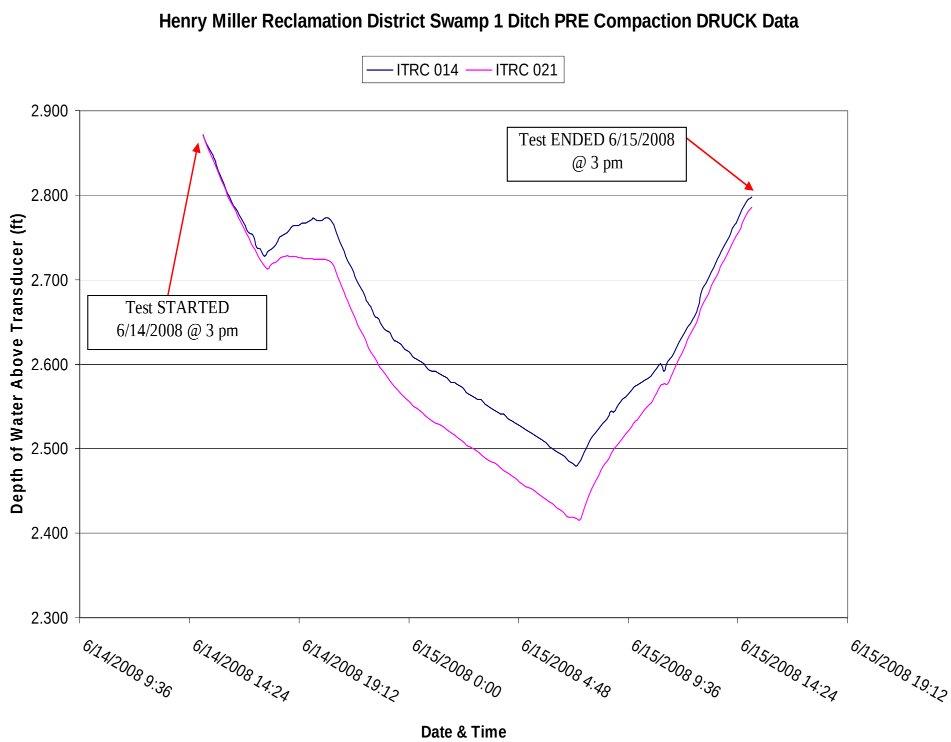

Figure 5. Pressure transducer (“Druck” brand) data for ponding test – San Luis Canal Co (Henry Miller RD)

Soil Preparation. During the first compaction work at Lateral H in James ID, it was learned that if the canal banks were first smoothed off, the compactor could operate much more quickly. Subsequent locations were therefore lightly smoothed off. There was no opportunity to obtain the “optimum” moisture content for compaction. Field conditions and availability required that the compactor begin work as soon as the canal had dried down enough to use the equipment without making mud. Certainly, moisture contents were different at various depths in the banks and bottom.

Laboratory Tests. Soil samples were taken in the field for a number of reasons. In some cases, undisturbed core samples were taken to measure bulk density before and after compaction. Texture samples (about 20 per canal section) were taken at various depths. Laboratory experiments were run with the Modified Proctor test to determine optimum lab moisture contents for compaction, and the effects on hydraulic conductivity. As noted earlier, the hydraulic conductivity measurements were inconclusive except to show that any amount of compaction drastically reduced to the hydraulic conductivity in the lab.

Equipment and Costs. The side soil was compacted using a 45-thousand pound Kobelco excavator with an MBW, Inc. UVW 36-inch roller attached to the end of the boom. Installed immediately between the UVW-36 roller and the end of the excavator boom was a UV-10K exciter. This exciter is a hydraulically driven vibration mechanism. Since the vibratory exciter was hydraulically driven, the excavator operator could engage and disengage the exciter when he felt it was necessary. For large canal bottoms, a ride-on unit was used (Fig. 4)

The compaction accessories cost about $25,000 (not including the cost of the excavator) installed. An experienced operator was able to compact the sides of 1 mile of canal (both sides, meaning 2 miles total) in about 8 days. The cost for the operator, transport of the excavator, and the excavator rental was about $1.20/foot of canal, with about 10 feet of compaction on each side of the canal (cost = $1200 for 1000’ long pool).

Figure 6. 36” vibratory roller (MBW, Inc.) attached to the end of an excavator arm.

Figure 7. Compacting the sides and bottom of Lateral H at James ID

Figure 8. Compacting the canal banks on the James ID main canal with an MBW vibratory roller

RESULTS

Table 2 shows the results of the in-situ compaction. Seepage reduction varied from 12% to 89%. Clearly, the three sites at which the canal bottom was compacted had much better results than the two sites at which only the sides were compacted. The seepage differences were probably due to additional factors, but this appears to be one possible explanation.

Table 2. Compaction results

Irrigation District	Location	Compaction		Cost, $	L, ft	Canal width, ft	Texture	Pre-Seepage GPM	Post-Seepage GPM	% Seepage Reduction
		Sides	Bottom							
Chowchilla WD	Site #2 – Ash Main Canal, between roads 11-12	Y	N	4,845	4,240	27	Loamy Sand	143	126	12*
James ID	Lateral H, from Main Canal to TO	Y	Y	3,240	1,010	15	Sandy Loam	86	12	86
James ID	Main Canal	Y	N	15,800	10,238	58	Sandy Loam	252	173	31
San Luis Canal Co.	Swamp 1 Ditch, between Turner Island & Deep Well	Y	Y	1,945	1,730	27	Sandy Loam	130	14	89
San Luis Canal Co.	East Delta Canal	Y	Y – with ride-on**	3,100	3,020	19	Loam	80	8	90

*The Chowchilla WD site had sections of rip-rap along the canal banks that could not be compacted, resulting in a lower % seepage reduction
** Ride-on indicates a large self-propelled unit

CONCLUSION

For sandy loam soils, in-situ compaction with a vibratory roller reduced seepage. The seepage reduction was significant (86 – 89%) when both the sides and bottom were compacted. The compaction extended to a depth of about 2 feet, so it is anticipated that the seepage reduction will withstand normal maintenance activities from year to year.

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COOPERATIVE EFFORT OF IRRIGATION COMPANIES LEADS TO WATER CONSERVATION

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ABSTRACT

The West Side Combined Canals Salinity Project (Combined Canals) was a multi-million dollar combined irrigation project that met the needs of two irrigation companies and the Ute and Ouray Indian Tribes. The Bureau of Indian Affairs (BIA), the Uintah River Irrigation Company (URIC), and the Ouray Park Irrigation Company (OPIC) had historically competed over the limited Uinta River water supply. A steering committee made up of representatives from these groups met monthly over the past decade to oversee and direct the development of the Combined Canals. The project involved working together to create one large pressurized distribution system, rather than merely laying pipe in the existing alignments of the seven participating canals. A memorandum of understanding was produced that defined operation of the combined system. A Supervisory Control and Data Acquisition (SCADA) system was implemented to allow project participants to monitor water usage and water accounting. Each entity was able to realize an increased water supply, an increase which may have been economically infeasible if implemented as individual projects.

INTRODUCTION

Background

Over a decade ago, an irrigation company in western Uintah County, Utah received funding to pipe their canal. When the irrigation company requested assistance, the Uintah Water Conservancy District (UWCD) realized the potential for other companies to receive similar benefit. The concept of the West Side Combined Canals Salinity Project (Combined Canals) was born. The result was a multi-million dollar combined irrigation project that met the needs of two irrigation companies and the Ute and Ouray Indian Tribes.

The Bureau of Indian Affairs (BIA), the Uintah River Irrigation Company (URIC), and the Ouray Park Irrigation Company (OPIC) had historically competed over the limited Uinta River water supply. Through the implementation of the Combined Canals, these entities realized that by working together thousands of acre feet of water could be conserved. By combining the various canal replacement projects, water conservation was

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achieved at a lower cost. Each entity was able to realize an increased water supply that may have been economically infeasible had they tried to implement an individual project.

Project Description

The final phase of the Combined Canals was put into operation during the irrigation season of 2008. The project delivers water to over 14,000 acres in three distinct areas within western Uintah County. The project, as shown in Figure 1, replaced 46.4 miles of 7 different canals or ditches with a 200-cfs diversion structure from the Uinta River, rehabilitation of the Cottonwood Reservoir outlet works, 8.3 miles of 48-inch diameter HDPE pipe, almost 7 miles of other large (24-inch to 36-inch) diameter pipe, and 21 miles of lateral pipelines. In order to accomplish a project of this magnitude, coordination with several agencies, including the U.S. Bureau of Reclamation, was necessary to obtain funding and establish environmental and ecological benefits.

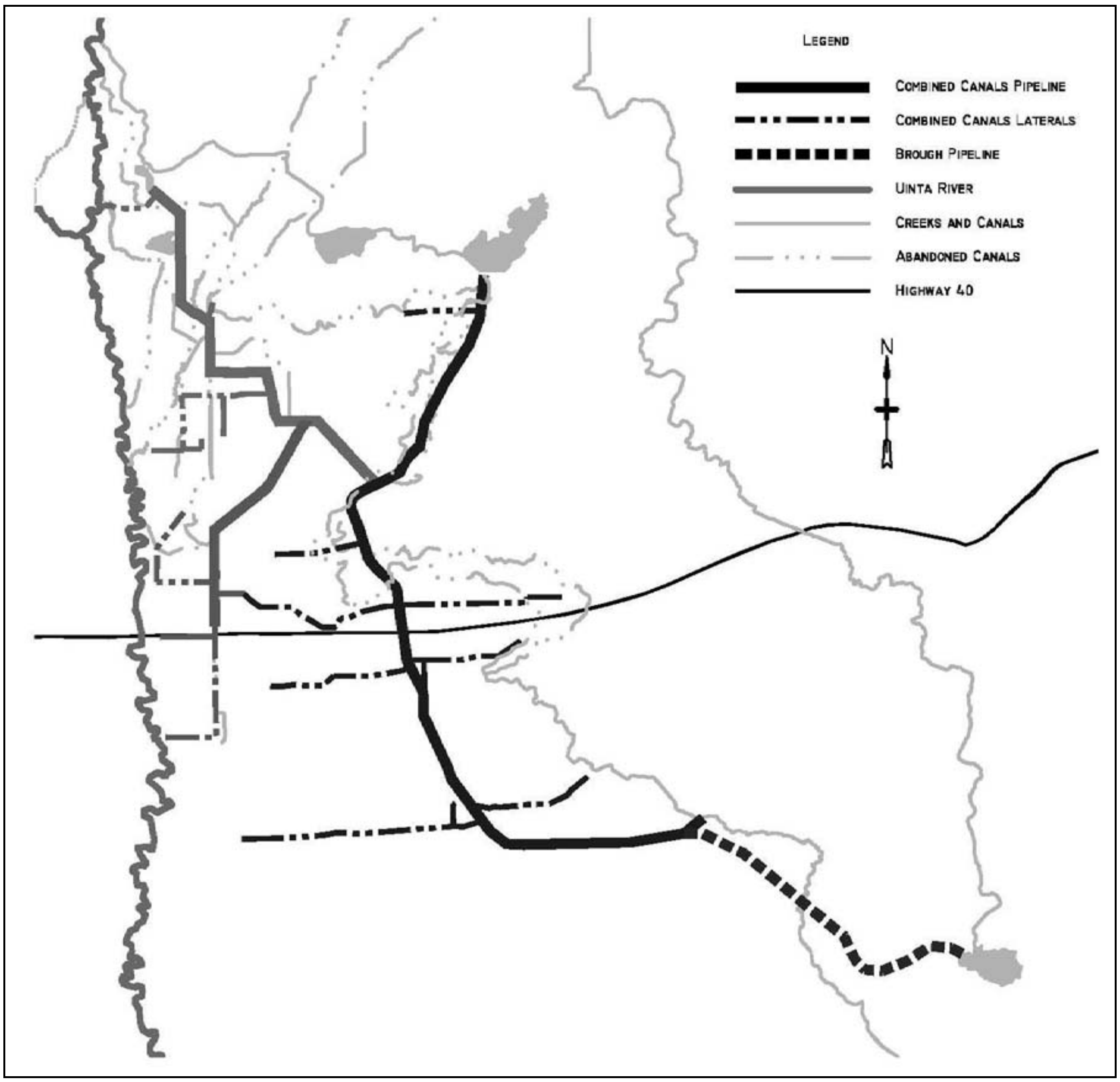

Figure 1. West Side Combined Canals Salinity Project

Purpose

This paper will discuss the significant water savings that are accruing due to the pipeline and operation factors of the project. The water supply is extremely limited in the area and thus the resulting increase of water due to the saved water has significant economic benefits to the irrigators. This paper also discusses the use of the SCADA System in the operation of the Combined Canals System and the significant operation costs that are saved due to the remote operation.

COOPERATIVE EFFORT

Before conception of the Combined Canals, the seven canals were owned and operated separately by two irrigation companies and the Ute and Ouray Indian Tribes. 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 Combined Canals to be successful, the irrigation companies and Tribes would have to work together to overcome many obstacles, all while achieving a technically innovative and socially acceptable design.

Memorandum of Understanding

The idea of a combined system was innovative because not only water but also water rights and system operation would be commingled. Having historically competed over a limited Uinta River water supply, people were not eager to participate. In order for the Combined Canals to succeed, system operation would need to ensure the honoring of existing water rights. A detailed Memorandum of Understanding (MOU) was negotiated and an extensive Supervisory Control and Data Acquisition (SCADA) system was implemented to allow the project participants to monitor water usage and water accounting.

Key items addressed in the MOU include:

- Honoring of existing water rights,
- Ownership of project facilities,
- Operation of project facilities,
- Storage in Cottonwood Reservoir,
- Operation and maintenance responsibilities by project participant, and
- Roles of steering committee members.

Steering Committee

The Combined Canals would not have been possible without the input from the project participants. One of the first steps of the project planning was to create a steering committee made up of representatives from UWCD, OPIC, URIC, and BIA. This group met monthly over the past decade to oversee and direct the development of the Combined Canals. They compromised and agreed to a memorandum of understanding and other water use agreements that defined the operation of the project. The committee also helped to make critical design choices presented by the engineer.

WATER CONSERVATION

As discussed later in the paper on improved water management, significant amounts of water are being saved by the project. Water is released from storage reservoirs only when it is needed. With a gravity canal system, the travel time of water is measured in hours. Thus, when time is needed to change water sets, the water continues down the ditch and much water is lost. Due to the use of pipelines and the Control system, very little water is lost to operational inefficiencies.

Abandonment of Canals

The Combined Canals resulted in the abandonment of all or part of seven canals. Table 1 lists the canals and the lengths of which have been abandoned.

Table 1. Abandoned Canals

Canal	Abandoned Length (miles)
Moffat	16.4
Ouray Park	13.8
Tabby White	2.5
Harris Ditch	5.9
Military Ditch	2.6
Deep Creek – Lateral 7	2.7
Daniels Ditch	1.0

In addition to the abandonment of the canals, a portion of the Ouray Park Canal was rehabilitated by lining it with a bentonite and geotextile liner.

Table 2. Lined Canal

Canal	Lined Length (miles)
Ouray Park Feeder	1.5

Seepage Loss

The seepage loss that has been conserved through the abandonment of the canals is tabulated in Table 3. The project has resulted in a total of almost 12,000 acre-feet (acft) of conserved water.

Table 3. Estimated Pre-Project Annual Seepage Loss

Canal	Length (miles)	Annual Flow (acft)	Estimated Loss (%/mile)	Estimated Loss per mile (acft/year)	Annual Seepage Loss (acft)
Moffat	16.4	8,330	2.7	227	3,715
Ouray Park Feeder	1.5	30,000		390	585
Ouray Park	13.8	30,000	1.5	453	6,253
Tabby White	2.5	890	7.0		156
Harris Ditch	5.9	890	4.0		210
Military Ditch	2.6	1,490	8.0		310
Deep Creek Lateral 7	2.7	3,270	4.0		353
Daniels Ditch	1.0	600		230	230
TOTAL	**46.4**	**45,470**			**11,812**

(total flow does not double count 30,000 acft for Ouray Park)

Conserved Water

The water supply is in the Combined Canals area is extremely limited. It has been estimated that the irrigators have increased their water supply by more than 25%, as shown in Table 3). Though this still leaves them short of water, the resulting increase of water due to the saved water has significant economic benefits to the irrigators.

USE OF SCADA TECHNOLOGY

The project was planned, designed, and constructed to use the latest in water measurement technology to allow for accurate water accounting. The measurement of water and accounting by user assures that the use of water is within the parameters of the original water rights. The extensive use of meters in an agricultural setting is an innovative but critical part of the success of this project. A SCADA system is usually thought of as just an operational need, but here it was absolutely critical.

While the water accounting is critical to the operation & success of the project, the project also uses the capabilities of SCADA by allowing remote operation at 6 critical points within the system. Due to the remote location of these points, some of which are accessible only by unimproved roads, travel times are measured in hours. Also the elevation difference from the beginning of the project to the last delivery point is over 500 feet over a 14 mile distance as the crow flies.

Why a SCADA system?

The three entities involved in this project have a very long history of mistrust and accusations of water stealing. Some of the accusations may have been well founded but the fact of the matter is that none of them had an accurate way to measure what they or the others were using. Each company had a measurement point from the Uinta River on their individual canal but these were seldom checked due to their remote location. When they were checked, the measurement was often an approximation by the ditch rider of the individual company whose tendency was to underestimate what was actually being taken.

The mistrust between the separate entities also filtered down to the individuals within the irrigation companies. Each individual would accuse those on the ditch upstream of them of taking more than their right. This determination was again an approximation by the ditch rider or by the landowners themselves and was more often than not estimated in their own favor. Because there were almost no actual measurement devices on the system, there was no way to determine who actually had taken more or less than their allotment for the year. This lead to a "take it when you can get it" mentality that turned neighbor against neighbor especially during dry water years.

Due to the mistrust and angst between and within irrigation companies, the three separate but parallel irrigation systems were not functioning efficiently. When the companies with the priority rights were not using all the water they were entitled to under their rights, they would send the water they were not using down the river instead of notifying the company with the next right that they could take more water. This waste of a precious resource was due to the poor management of the resource and a reluctance to communicate between the irrigation companies.

Even on good water years, when there was more than enough water to go around, there was confusion as to who could take the high spring runoff, who could store it and how much each company could use. During years like this the water distribution was a free for all with companies and individuals taking everything they could get without respect to water rights.

Because of the mistrust and inefficient operation of the systems it was determined very early in the design process that a system for accurate water measurement and accounting would be necessary and critical to the success of a combined project in the area. This system would have to be in the control of a neutral third party that had the authority to make the hard decisions during dry water years.

What will a SCADA system do?

The system would have to achieve three main purposes in order for the project to be successful for all entities involved. The system would, first, have to accurately measure the water for all three irrigation companies and for the individual water users, facilitating the efficient use and distribution of the limited water. Secondly, the system must add ease of operation for the ditch rider to cut down on the wasted time driving from one site to another. Third, the information gathered by the system must be made public so that individual water users could see that the water was being distributed fairly. This last purpose would create local accountability, with each water user knowing exactly what their neighbors are using.

From the purposes and needs defined for the system it was obvious that a complex Supervisory Control and Data Acquisition (SCADA) system would be needed. The

SCADA system would have to be composed of measurement devices for accurate water measurement, a series of dataloggers and radios to relay the collected data and a central computer (Host) to gather and display all the data for the irrigation system. The system would also need remote operable valves at critical locations in the water system that could be opened or shut from the Host computer.

Water Accounting

With this system in place, the three main purposes could be achieved. The place of diversion for all three companies water rights were moved to a single diversion at the head of the Ouray Park Canal. The headgate at this diversion was automated but the control of this gate was not connected to the project SCADA system but rather was connected to a system run by the Uinta River Commissioner. He controls all the diversions from the river and is in charge of distributing the water in the river according to water rights of the companies. A large concrete flume was built at the same diversion location to accurately measure the full diversion amount that is to be divided between the three irrigation companies.

From here the water flows down the Ouray Park Canal and into Cottonwood Reservoir. There is only one diversion along the main canal and that feeds into the BIA Inlet pond. This pond acts as a regulating pond for the entire BIA system. Cottonwood Reservoir acts as the regulator for the pipeline that feeds the URIC and OPIC irrigation systems. There is a flume at the Inlet Pond diversion to measure what the BIA is using. There are magmeters at the outlets of the Inlet Pond and Cottonwood Reservoir to measure what is being taken from the reservoirs.

Every lateral from the main pipelines of the system have a magmeter connected to the SCADA system. The data from all of these individual SCADA sites are transmitted to the Host computer. Calculations are programmed into the Host so that at any point in time it displays the current flow reading at each measurement point within the system and also displays the total flow being taken by each irrigation company. This facilitates the correct operation of the system by company water right. The access to the information on the Host computer is limited to the system operators and the Presidents of the individual irrigation companies.

Along each lateral there are meters for each individual turnout. These meters are not connected to the SCADA system but are manually read monthly as a check for the Lateral SCADA meter and also to account for the individual water used. This allows for accurate determination of when one water user on a lateral has used his allotted amount of water and how much another may still have the right to. Using the SCADA system meters as tools, individual and company water accounting can be achieved quite easily.

Operation

In order to make the system operator's job possible within a normal workday several other tools were implemented within the SCADA system. Using the data received from the meters along the pipeline it is possible to diagnose flow problems and check for leaks in the pipeline. Several meters were installed at strategic points in the pipeline with the sole purpose of creating a point of reference or a check on the pipeline. These additional meters have also helped diagnose problems with the SCADA system itself, such as a bad meter or a faulty radio.

In addition to the flow data received by the Host, several other critical system readings are measured and communicated to the Host. The level of the Inlet Pond and Cottonwood Reservoir can also be monitored through the Host Computer. Pressure transducers are installed in each reservoir which are connected to the SCADA system. The elevation data is displayed at the host but more importantly, the Host computer has a system of alarms that will alert the system operator by phone if the reservoir level is too high or too low.

Pressure transducers are installed at strategic locations along the pipeline. Due to the large elevation drop along the length of the pipeline, several pressure reducing valves (PRV's) have been installed to regulate system pressures in the mainline and to the individual laterals. Pressure transducers are installed on the upstream and downstream sides of these PRV's to quickly monitor and report potentially damaging pressure situations. The Host alarms are also set for the pressure in the pipeline so that if there is a pressure surge above the safe operating pressure or if there is a PRV failure, the Host will immediately call the system operator to alert him to the condition. Quick response time by the operator after being alerted by the Host may save thousands in repair costs to the pipeline each year.

There are three critical valves along the pipeline system that can be operated remotely. There are a couple purposes for automating some of the valves along the pipeline. One purpose is to be able to open and close often used valves in remote locations without having to travel to the site each time. This literally saves hours and hours of driving time each day. The second purpose is to be able to respond quickly to open or close a valve when there is a problem with the pipeline system. The three automated valves are located at the beginning and end of the URIC/OPIC pipeline and at the Inlet Pond diversion from the Ouray Park Canal. Although the Host site is available to the company presidents, the only one with authority to open or close these automated valves is the system operator. Individual logins with different access rights have been set up to ensure the consistent operation of the system.

Figure 2. Pressure Reducing Valve Vault

Local Accountability

In order to make the data on the Host computer available to the general public a website was created that shows the current flows to each lateral. Only one person can be logged on to the Host computer at a time and having a login for the general public, even with very restricted access, would often make it unavailable to the system operator when he needed to check the system or operate the automated valves. A website was the obvious solution to this dilemma. The website pulls the data from the Host computer once an hour.

A call-in number has also been set up on the host computer so that those water users in the area that do not have a computer can call by phone and with the proper codes, can hear the current flows to the laterals. In this manner, anyone that wants to know what the flow is anywhere in the system has a way to find out.

Example Problems

Although SCADA systems are becoming quite common among municipal water systems, to find one this complex on a local irrigation system is almost unheard of. There are three specific examples within this system of creative uses of the capabilities of a SCADA system as it applies to irrigation systems.

Inlet Pond Level Control

The Inlet Pond for the BIA system is an approximately 40 acft pond. The average flow in a high water demand year through this pond could possibly reach 30 cfs. The size of this pond for the amount of water that is used from it causes it to drain quite quickly. In the past, there have been several times when the pond has gone dry and the pipeline has partially drained before the ditch rider was aware of the problem. Maintaining a consistent level in this pond manually is almost a full time job in itself.

In order to eliminate this problem, an automated gate was installed on the inlet to this pond at the diversion from the Ouray Park Canal. This gate was programmed to work with the pressure transducer that records the level of the pond. When the level of the pond had dropped a foot from the spillway level the gate on the canal begins to open. It continues to slowly open until the pond is at the spillway. When the pond reaches this level the gate closes to prevent losses over the spillway. This programming can be overridden from the Host. If for some reason the system operator wants to drain the pond, he can manually close the headgate.

Using this automatic level control, the system operator was able to specify the high and low set-points of the pond from the Host and the pond regulates itself. The pond regulated itself the entire summer of 2008 without any losses over the spillway and with no problems with draining the pond.

Figure 3. Inlet Pond Automated Gate

Cottonwood Reservoir Elevation Measurement

In order to get an accurate water level measurement from Cottonwood for the SCADA system there were several options. A conduit and pressure transducer could have been run up and over the dam, down the upstream face of the dam to the bottom of the reservoir. This would have been very costly and time consuming and would have required the approval and regulation of the Utah Division of Dam Safety. A deep stilling well could have been used but would have had the same negative aspects as the conduit with the addition of icing problems in the winter.

It was decided to place a pressure transducer in the pipeline at the downstream toe of the dam. There is a large vault at the toe of the dam that houses the automated valve and meter for the pipeline. There is a SCADA site already installed at this location so adding a pressure transducer reading to the data being sent to the Host was not a problem. The problem is that at this location, the only time that we would get a true elevation reading for the reservoir was when there was no water running through the outlet conduit of the dam into the pipeline. This would only happen at the end of the water year when the reservoir was down to the legal deadpool level.

In order to solve this problem, the pressure in the pipeline had to be used in conjunction with the flow through the pipeline and a headloss calculation in order to get an accurate level reading with flowing water. Using the energy equation with estimated minor losses for the inlet screen and steel pipe, the host is able to calculate an accurate water level. The calculation was monitored throughout the summer and the largest variation from the actual reservoir elevation was 6 inches and the average error was about 3 inches. With 60 feet of elevation difference from top to bottom, that is a very acceptable error. The Host computer simply displays the elevation of the reservoir.

The use of the SCADA data and the correct calculations saved the cost of placing a much more expensive level measurement system. Having the pressure transducer in the vault and attached to the outside of the pipe also protects it from corrosion or silting. It also makes it much easier to remove and replace if necessary making the maintenance of the transducer almost nothing as compared to a transducer on the upstream side of the dam.

Brough Vault Control Valves

The Brough Vault is located at the opposite end of the pipeline as the Cottonwood Vault. The Brough Vault controls the flow of water out the end of the pipeline. This water then discharges back into the Ouray Park Canal and continues south to other OPIC water users and to Pelican Lake. Because this canal serves several water users during the summer, the flow to the canal changes almost daily as the water users turn their irrigation systems off and on. The location of this vault is very remote, being about 20 minutes from any paved road. The only power line in the area is a 500KV line on 100 foot tall towers.

Control valves had to be placed in this vault to maintain pressure in the pipeline upstream and accurately control the flow to the canal at anywhere from 5 to 70cfs, but had to run

on a battery and solar panel system. Running a power line to the area would have been cost prohibitive. With only DC power available, Globe valves were the only good option since they use the water pressure in the system to open and close rather than an outside source of AC power. The globe valves were installed and connected to the SCADA system.
(picture)

The selection and installation of the valves was just the first hurdle to make these valves function properly. Because globe valves use the pipeline pressure to open and close, they will not move if there is no pressure on the pipeline. Because these valves are at the end of the pipeline and at the bottom of a large hill, if they were opened too much they could easily bleed off the pressure and render themselves useless. A system operator would then have to travel to the site and close the butterfly valves in the vault manually in order to build pressure before the globe valves would work again. A series of safeties was programmed into the SCADA system at this site to ensure that the pressure in the system never dropped below 20psi. If the pipeline drops below 20 psi, the SCADA system closes the valve a little at a time automatically until it maintains 20 psi. This safety can be overridden in the vault if the system operator needs to drain the pipeline.

The SCADA system was also programmed with a high pressure safety in case of a failed PRV valve upstream. If the pressure of the system rises above safe levels, the SCADA system automatically opens the valve a little at a time until the safe pressure is maintained. If a high or low pressure situation arises, the Host computer phones the system operator to let him know something is wrong.

During testing of the globe valves, we discovered that when the SCADA system sent the initial signal to open or close the valve, that the valve would quickly open up too far and would have to close back down to reach the desired setpoint. This was especially true when flows of over 40cfs were going through the pipeline. This would cause unstable pressure fluctuations and would have possibly caused water hammer damage to the pipeline. To offset this quick initial opening, a delay was programmed into the SCADA system so that it would send the signal to open for 1 second and then would wait for the valve to equalize for 15 seconds before sending another 1 second open signal if necessary. It continues to send 1 second signals and 15 second delays until the valve is at the desired setpoint.

<u>Problems Summary</u>

In each of these cases, the SCADA system was able to automatically control and operate parts of the irrigation system that would have required a lot of manual operation and time by a system operator to maintain. Add to that the time saved in normal operation of the irrigation system by reducing driving time and minimizing manual system checking and the value of a SCADA system starts to reveal itself. Although a SCADA system requires capital expenditures at the onset of a project, the time and money that it saves on operation and maintenance of a pipeline is well worth it. In this case, an irrigation system that used to have three full time ditch riders can be operated by a single system operator.

SUMMARY

The attitude and willingness of the local irrigators to work together in developing this project has resulted in significant water savings to them. The reduced losses are from two major sources. The first is due to reduced seepage and evapotranspiration by converting from open ditches and canals to pipelines. The second is due to operational savings by having better control of the water. While reliable pre-project measurements are not available, conservative estimates would indicate that over 25% of their water supply are being saved. These water savings are being used towards meeting the shortages which they had before the project.

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ELEMENTS OF SUSTAINABILITY AFFECTING THE CENTRAL OREGON IRRIGATION DISTRICT

Steve Johnson[1]
Herbert G. Blank[2]

ABSTRACT

Established in 1918, the Central Oregon Irrigation District (COID) is a Municipal Corporation of the State of Oregon. The system consists of two main canals: the Pilot Butte Canal, which runs north through Bend, Redmond and Terrebonne; and the Central Oregon Canal, which runs east through Bend, Alfalfa and Powell Butte. Both canals divert water from the Deschutes River. The District provides water to 3,600 deliveries through more than 700 miles of canals for about 45,000 acres within an 180,000 acre area in Central Oregon. In addition, COID provides water to the City of Redmond and numerous subdivisions; in Bend, many parks and schools receive water through the COID system. The paper addresses how COID is dealing with the issues of urbanization, environmental priorities, conversion of water rights and other issues affecting the sustainability of the District. Factors include the changing client base, dialogue with federal and state agencies, municipalities, environmental groups and patrons, employment of labor saving technologies, water conservation, and diversification of business interests.

CURRENT CONDITIONS

The major sustainability challenges facing COID are urbanization and environmental concerns coupled with possible liabilities resulting from the Endangered Species Act (ESA). The cities of Bend and Redmond have extended their urban growth boundaries (UGB) which have resulted in the conversion of irrigated acreage into new subdivisions and other urban uses. The most recent UGB expansion of the City of Redmond will affect 2,340 irrigated acres and the proposed Bend UGB another 1,240 irrigated acres. Environmental factors are increasingly becoming a priority with the reintroduction of ESA listed fish species and the liabilities which may occur. COID is constantly dealing with a changing client base as more patrons are "lifestyle farmers." All of these factors must be addressed in developing strategies to sustain the District through the twenty first century.

Limited Assessment Base

Like other irrigation districts, COID has a limited assessment base. There is little or no potential for expansion of irrigated acreage, rather the pressure is the other way: irrigated land is taken out of production and converted to residential development as urban areas expand. The history of Central Oregon is basically that of irrigation development. The Carey Act of 1894, stimulated private development of irrigation systems throughout the

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West and resulted in land development through the provision of irrigation canals in Central Oregon. While the irrigated land was allocated to settlers in 160 acre parcels, the remainder of the land, particularly in Deschutes Country, remains under Federal ownership, either as National Forest or under the Bureau of Land Management, with approximately 70 per cent of land in the county under federal jurisdiction. With these restrictions on development of new land and Oregon's land use laws, any residential population growth in the area comes at the expense of irrigated acreage. Since the vast majority of developable land lies in irrigation districts, it is incumbent upon irrigation district managers to be involved in local government planning activities.

While there has been some division of parcels resulting in an increase in the number of assessments, there is little potential for managing this to increase revenue. Also, the district has limited ability to increase assessments. Increases must be approved by the elected Board of Directors who are generally reluctant to make major changes that would financially burden patrons. Thus, the District faces limited growth in revenue through its core business of supplying water to irrigation patrons while wrestling with the ever increasing costs and regulations of operating a complex irrigation system.

Labor Intensive Nature of Irrigation Districts

Like most irrigation districts, COID is a labor intensive operation. Approximately 80 per cent of the District's expenditures are employee related. While efforts have been made to reduce the number of employees, there is a limit to the number of positions that can be eliminated while still providing essential services to patrons. Also, for every position eliminated, increases in employee expenses soon override those savings.

Technology can play a role in increasing employee efficiency. For example, automation of gate operations and the use of GIS have been employed by COID and significant improvements in efficiency have been noted, but on the other hand, there are activities, such as annual removal of sediment and tumbleweeds from canals, which can only be done manually.

Changing Environmental Values

Although surface water rights in the Deschutes River were fully appropriated by 1913, giving irrigation districts the legal authority to literally dry up the natural flow of the river in the summer months, this practice is no longer acceptable. Due to various actions water flow in the Deschutes has significantly increased over the past ten years. State laws have been changed, particularly the Oregon Conserved Water Act of 1973 (see Blank et al 2004), which promote the return of conserved water to the river. The Deschutes River Conservancy (DRC) has purchased and leased water rights in cooperation with irrigation districts to return temporary and permanent flow into the rivers of Central Oregon.

Under the Wild and Scenic Rivers Act of 1968, various segments of Central Oregon rivers have been classified as National Wild and Scenic Rivers. The purpose of the Act was to provide some level of protection based on a river's outstanding recreational, scenic or other values. Oregon expanded the federal list of rivers with the Omnibus Rivers Bill in 1988. Furthermore, the Endangered Species Act (ESA) has provided protection to listed species including bull trout and steelhead (Mid-C) in the Deschutes River.

Reintroduction of steelhead trout in sections of the Deschutes basin has occurred over the past two years. Because steelhead are a threatened species under the ESA, any entity in the basin that has operations that could negatively affect the species is potentially liable to enforcement actions with criminal and civil penalties. Since 2007, COID and other irrigation districts in the basin have been working with congressional representatives and over 20 stakeholder groups including federal and state agencies, Indian tribes, and a variety of conservation and environmental organizations to prepare a Habitat Conservation Plan (HCP). An HCP, once approved, would allow issuance of Incidental Take Permits (ITP) for listed species and provide liability protection to the districts.

While preparation of the HCP is a long term process estimated to take at least seven years, the National Marine and Fisheries Service (NMFS), which is responsible for the conservation and management of anadromous fish, including steelhead and salmon, has recognized COID and other irrigation districts for their continuing conservation work and has issued Letters of Prosecutorial Discretion stating that NMFS will not pursue any legal actions as long as this work continues (COID, 2008). The Letters of Prosecutorial Discretion expire in May 2010.

COID has been successful in developing and implementing a strategy that can support the reintroduction of steelhead and at the same time diminish the chances of adverse legal actions. This strategy, although time consuming, manpower intensive and expensive, helps assure the sustainability of the district, providing it a seat at the table and assuring that the district will have a voice in decisions that affect planning in the region.

Changing Role of Agriculture

As discussed in an earlier paper (Blank and Johnson, 2005), Deschutes county remains one of the fastest growing counties in Oregon, with a 9.4% annual growth rate between 2000 and 2007 (U.S. Census Bureau, 2007). Although the region is now undergoing a lull in growth, the trend toward urbanization continues. Agriculture, as a result, has undergone a substantive change, with a shift from commercial to “lifestyle” farming, where the major income of farm owners is off-farm. An indication of this is the reduction in parcel size among COID patrons. Despite Oregon’s land use planning laws which were intended to restrict subdivision of land outside designated urban growth areas, subdivision has occurred. At the time of settlement in the early 1900s settlers were allocated 160 acre parcels, only two of which are left fully intact in the COID service area. The average parcel size is now 9 acres, with the median less than 5 acres. Fully 87% of the parcels receiving irrigation water in COID are 20 acres or less in size and constitute 68% of the total irrigated acreage.

Our paper presented in 2005, included data from the Census of Agriculture through 2002. The 2007 census is now available (USDA, 2007) and some interesting changes in the trends have occurred. The number of horses and ponies, which had increased dramatically in 2002 to 5,695 decreased by 23% to 4,369 in 2007, which, although larger than the state trend which shows a decrease of 3.3%, may be associated with increasing cost of feed (See Figure 1). Hay and alfalfa costs in the county have roughly doubled over the past three years (USDA 2005 and 2008b). Furthermore, hay and alfalfa acreage has decreased slightly in the county from 22,578 acres in 2002 to 21,102 in 2007. Irrigated land has decreased significantly, from 44,436 acres in 2002 to 37,821 acres in 2007, a decrease of 15% over the five year period. This may be attributed to higher costs of production and the increasing number of irrigators either permanently selling water rights or temporarily leasing water for environmental reasons or transferring water to other uses. The number of irrigated acres in pasture has decreased as well as the percentage of irrigated land in pasture.

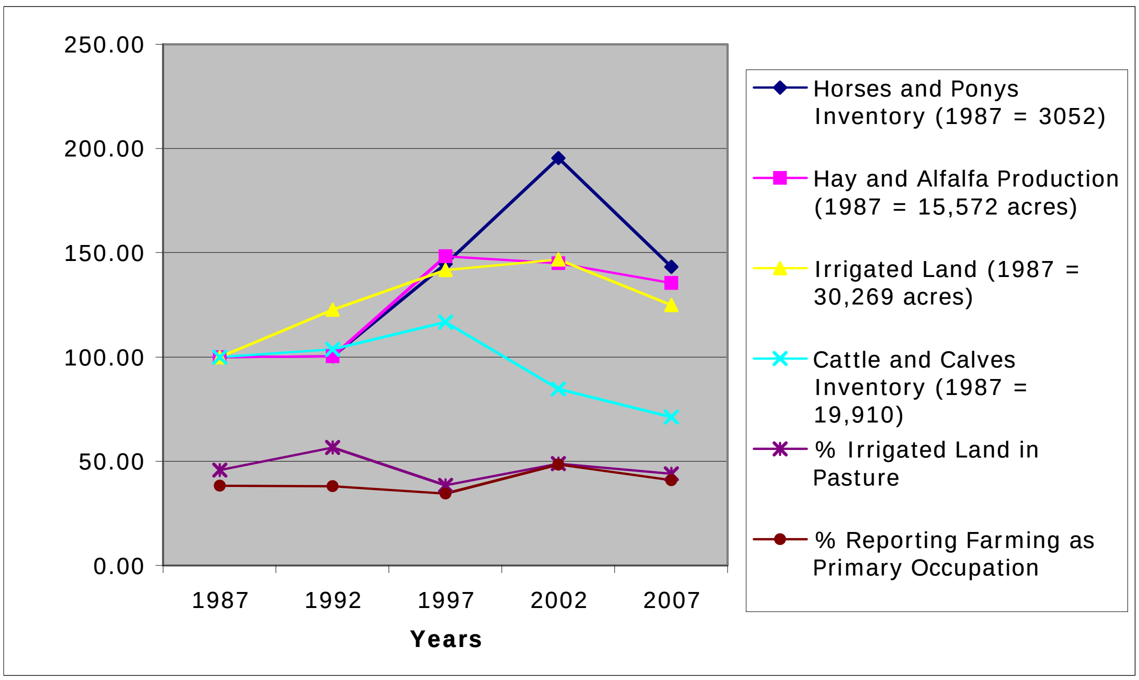

Figure 1. Changing Characteristics of Agriculture in Deschutes County, Oregon, (source USDA Census of Agriculture)

The number of respondents reporting farming as their primary occupation decreased from 789 to 573 and in percentage terms those reporting farming as their primary occupation decreased from 48% to 41% over the five year period. This also may be a signal of the decreasing profitability of agriculture in the region and the pressure of urbanization on agricultural land. With the number of farmers who report farming as their primary occupation decreasing in absolute and percentage terms, the number of farmers who report "Other" as their primary occupation have tended to increase over the 20 year period (see Figure 2).

The Deschutes county figures are not directly tied to COID patrons since there is substantial irrigated acreage within the county outside the COID service area, some in other irrigation districts and some, primarily from ground water, which is not associated with any irrigation district. Also, COID irrigates approximately 45,000 acres, roughly two thirds of this acreage is in Deschutes County, one third in Crook County and 300 acres in Jefferson County. Overall, the USDA figures appear to confirm the general situation of the COID service area: that agriculture is becoming less important to the economy and that "lifestyle" farmers have become the majority of water users in the district.

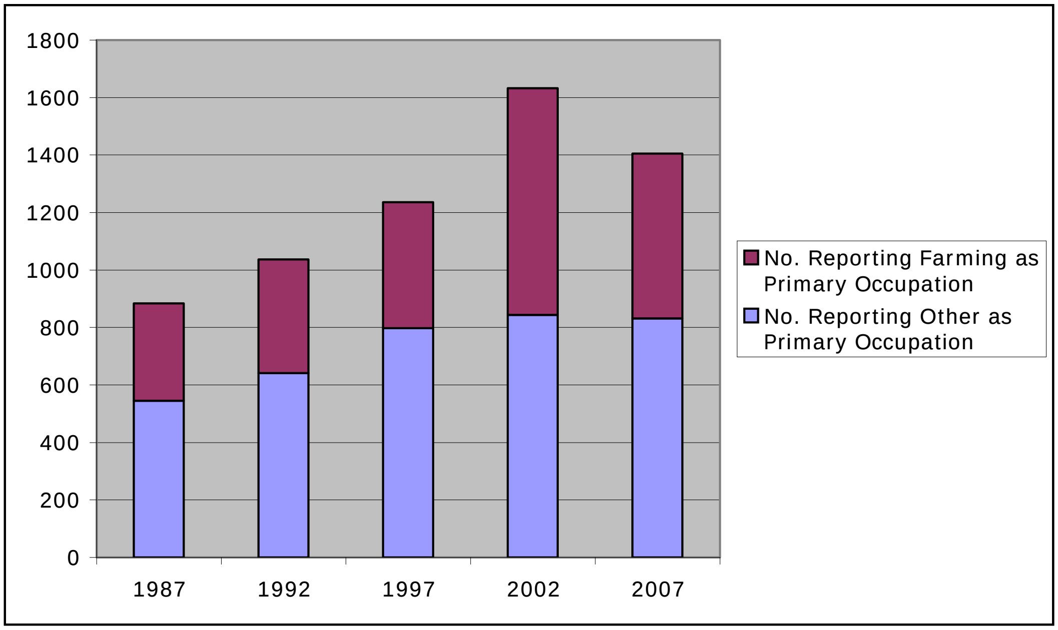

Figure 2. Numbers Reporting "Farming" and "Other" as their Primary Occupation, Deschutes County, Oregon (source USDA Census of Agriculture)

RESPONSES

Coordination among Irrigation Districts

The irrigation districts in central Oregon formally recognized common interests and joined together under Oregon statutes as the Deschutes Basin Board of Control (DBBC) in 2002. As a formal legal entity, the districts can pool their resources and collectively address common issues and concerns with a unified voice. The DBBC structure has proven very useful in addressing a number of issues including the pursuit of a Habitat Conservation Plan (HCP) for listed species recently reintroduced to the basin. The costs of pursuing an HCP on an individual basis would be onerous, but manageable with all the DBBC districts contributing.

Coordination with Local Government

The Deschutes Water Alliance (DWA) was formed in 2004 with the assistance of a Bureau of Reclamation Water 2025 grant to plan for long term water resource management in the Deschutes Basin. The DWA mission statement is to meet demands for water in the basin through the cooperation and voluntary participation of the key water suppliers and users. The Deschutes Water Alliance is entirely based on voluntary cooperation. There is no specific legal status for the DWA as a separate organization apart from the sum of its member entities authorities. The Deschutes Water Alliance is comprised of the following stakeholders:

The Deschutes Basin Board of Control (DBBC): an association of irrigation districts that includes North Unit, Central Oregon, Swalley, Tumalo, Three Sisters, Arnold, and Ochoco.

The Confederated Tribes of Warm Springs (CTWS): focused on managing resources as sustainable assets available for cultural, subsistence, economic and social purposes

Deschutes River Conservancy (DRC): a non-profit organization with a mission to restore stream flow and improve water quality in the Deschutes Basin.

Central Oregon Cities Organization (COCO): includes representatives from the cities of Bend, Culver, Madras, Maupin, Metolius, Prineville, Redmond, and Sisters.

The mission of the DWA is to (1) move stream flows toward a more natural hydrograph while securing and maintaining improved instream flows and water quality to support fish and wildlife, (2) secure and maintain a reliable and affordable supply of water to sustain agriculture and (3) secure a safe, affordable, and high quality water supply for urban communities.

The DWA serves as a means for the irrigation districts to receive recognition and fully participate in regional water planning activities. It provides a formal means for districts to coordinate with cities in meeting increasing demands for municipal and industrial water in the region. Deschutes County is now in the process up updating their Comprehensive Plan and the DWA will be involved in that process.

The DRC collaborated with local irrigation districts, cities, and water providers to form the Deschutes Water Alliance Water Bank (DWA Bank) in 2006. The DWA Bank moves temporary and permanent water between agricultural, municipal, and environmental uses to meet everyone's long-term water needs. Participation in the Bank is voluntary and the water rights involved with the water bank transactions are covered by existing State statutes. COID has been instrumental in creating and participating in the DWA Bank, which is the first water bank in the United States to bring cities, irrigation districts, river restoration and tribal interests together for the purpose of permanent water right transfers. While the priority of COID is to keep irrigation water rights “on the ground”, the fact is there is not enough demand from agriculture to absorb the amount of irrigation rights being affected by land sales and development. Transferring district water rights through the DWA Bank to primarily municipalities and river restoration parties insures financial sustainability of the district while moving water to higher valued uses through the payment of an exit fee placed on each DWA Bank transferred acre.

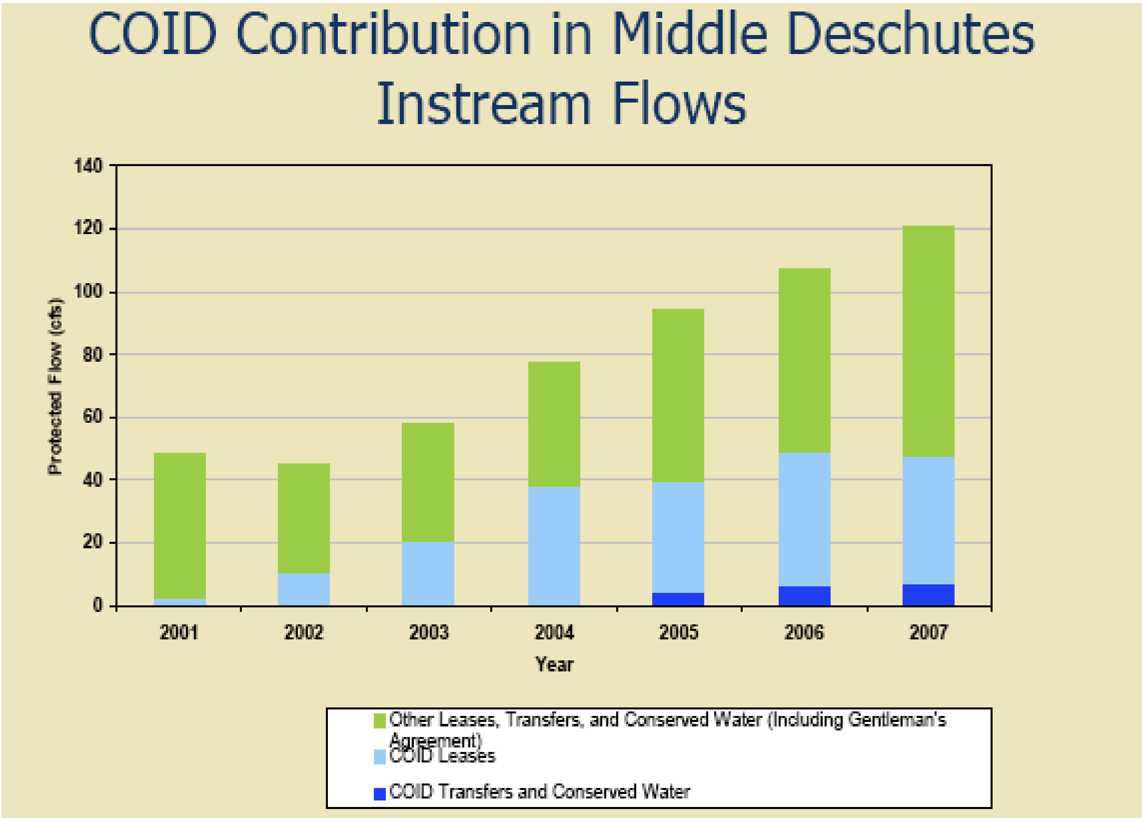

Figure 3. COID Contribution to Middle Deschutes Instream Flows
(Courtesy Deschutes River Conservancy)

As the number of assessed acres declines, the reduction in the assessment base could place a financial burden on the district and its patrons. To insure that the district's financial health does not suffer in the process, COID has instituted an exit fee cash payment which offsets the "lost" financial carrying capacity of each acre of water right. The exit fee is calculated based on a financial formula of the annual operating budget divided by the number of assessed acres to get an equivalent financial contribution of each assessed acre. The per acre financial contribution is then divided by the 10-Year U.S. Treasury Note interest rate to yield an effective amount of "principal" that if invested yields an income stream equivalent to the annual assessment. The amount of "principal" plus the per acre amount of any existing district debt yields the amount of lump sum cash amount paid to the district as its permanent exit fee. The exit fee for COID is now $1,538 per acre of water right and has been levied and paid since 2006 on a total of 489 acres that have exited the district through the DWA Bank. According to District policy, exit fee payments are placed permanently into the district's Endowment Fund where investment income is generated to cover the original assessment revenue. Surface water transfers within the district are not assessed the exit fee since the annual O&M assessment continues to be paid.

COID actively purchases -- at market rates -- water rights from its patron base and holds them in reserve to be available first for irrigation patrons. Once reserve levels, as set by the Board of Directors, are filled the district then allocates any surplus acres to the DWA Bank for the municipal and river restoration buyers. The reserve has now grown to several hundred acres and serves as an effective buffer to changing market conditions and demand within its patron base. All parties acquiring COID related water rights also sign an agreement to pay the corresponding District exit fees. The first transactions of the DWA Bank amounted to a little more than 80 acres and were completed in the last half of 2006. The number of water right acres transferred through the DWA Bank in 2007 and 2008 has averaged 204 acres. Due to slowed development a lesser amount is anticipated in 2009.

Oregon state law requires that any new ground water development in the Deschutes basin must mitigate with an equal amount of water returned to the river (Blank and Gorman, 2006). What this means, generally, is that the developer of a new ground water right must buy an existing surface water right. This is accomplished by either taking land out of agricultural production or from urban development and returning that amount of water permanently to the river. Most new water use applications are for groundwater sources requiring mitigation which puts pressure on existing surface irrigators, including COID patrons, to sell their surface water rights. While all water right transfers require the District's consent, the lack of agricultural demand for the use of the surface rights places the District in the position of utilizing the DWA Bank to insure its financial stability. The exit fee also protects the District from excessive losses of water rights due to this pressure.

Renewable Energy Development

COID built and licensed a 5.5 megawatt hydropower facility in 1989 and is moving ahead on two additional hydro units. The existing facility, located south of Bend, makes use of water diverted from the Deschutes River and returned to the river downstream. Since the diversion can only be operated above a minimum flow amount, the plant does not generally operate year round. The plant contributes substantial revenue to the district for its use to stabilize patron assessments, procure equipment and provide funding for piping and other capital improvement projects.

Piping not only conserves water by preventing the loss of water through the fractured basalt canals, which occur through out the distribution system, it also provides an opportunity for harnessing the energy potential, and therefore revenues, of the irrigation water flows and elevation drops in the canal system. COID's Pilot Butte Canal has a 700 foot elevation drop along the 14 mile distance between Bend and Redmond and could theoretically generate 12 megawatts of hydro power. COID is moving forward in the fall of 2009 with plans to pipe 2.5 miles of this distance for its Juniper Ridge Piping and Hydroelectric Project. This project will yield a hydro generating capacity of 3.8 megawatts when completed in the spring of 2010 and place 20 cfs of conserved water permanently in the Deschutes River.

With higher flows in the Middle Deschutes the feasibility of hydropower generation at a retired hydro facility at Cline Falls near Redmond is also being re-examined by COID. COID is evaluating the feasibility of licensing thru FERC and the State of Oregon to allow generation of hydroelectricity at that site. Analysis and evaluation of the costs of licensing are currently under review and so far the project has received favorable reviews from the Department of Environmental Quality and the Oregon Department of Fish and Wildlife.

In addition to other benefits of piping, COID is involved with canal safety and the role that piping may play. This involvement includes evaluation of liability considerations with the Special Districts Association of Oregon (SDAO) in addition to evaluating what existing statutory authorities allow for the payment of piping projects by developers or perceived benefactors of improved safety. The initial legal evaluation is that the funding question is still unanswered and that the municipalities are not embracing the discussion.

Water Wholesaling

One option for irrigation districts which are faced with losing patrons is to become a water wholesaler, selling available water to municipal providers. Under Oregon law irrigation districts can provide 99 year leases to municipalities. One difficulty is that irrigation district's water rights are for irrigation, which is only for the irrigation season, not for year round operation. A confounding factor is that irrigation districts don't generally hold water rights, the water rights are held by individual land owners within the District. The COID water right reserve program within the DWA Bank does provide a means whereby COID can purchase water rights from patrons and lease water to municipalities or other users who need water for the growing population of the area.

Endowment Fund

COID owns a substantial amount of land, both rights-of-way and irrigable land, some of which was foreclosed upon during the Depression. The District has undertaken a more energetic posture to sell a small assortment of parcels it owns to generate cash that is then placed in the Endowment Fund established with the exit fees previously mentioned. The Endowment Fund now has an invested balance of approximately $2,000,000. The interest from the fund, which is invested primarily in Certificate of Deposits and Bonds per State of Oregon statutes, is included in the District's budget and effectively subsidizes operations and maintenance costs, keeping patron assessments lower than would otherwise be the case. Managing the district's portfolio of land and funds is an increasingly important activity.

CONCLUSIONS

The paper has addressed how COID is dealing with the issues of urbanization, environmental priorities, conversion of water rights and other issues affecting the sustainability of the District. There are a number of aspects of sustainability which need to be addressed as part of an overall management strategy. In the case of COID, these include addressing the changing patron base to better provide service; proactive dialogue with regulatory agencies, municipalities, environmental groups and patrons in order to have a voice in planning activities; and employment of labor saving technologies, water conservation and diversification of business interests in order to improve efficiency of operations.

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DEALING WITH AN UNCERTAIN WATER SUPPLY IN JAMES IRRIGATION DISTRICT

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Brian E. Ehlers[2]
John Mallyon[3]

ABSTRACT

Based on the ongoing drought conditions and pumping restrictions from the Sacramento-San Joaquin River Delta (Delta), the James Irrigation District (District) made the decision to analyze their water resources to understand if the District could sustain its current agricultural practices without a Delta supply. The result of the analysis is that the District can continue to farm at its current capacity, but it will require changes to both District infrastructure and operations. Groundwater supplies can meet the overall demand of the District, but wells alone lack the instantaneous capacity to meet peak demand during summer months. Because of this, storage will be required to meet peak demands. Many options were developed and considered by the District. The final decision consisted of drilling additional wells, utilization of three large existing basins at the upstream end of the District for short-term storage, and system automation. Since the District does not rely on computerized controls, it is proposed that this design utilize simple robust structures, and minimal computerized automation, to provide a simple "automatic" control system to meet demands.

Other than design and engineering, significant project issues consisting of environmental concerns, cultural resources, and funding have arisen.

When completed, this project will provide for continued sustainable farming, remove the art of system control by implementing simple control systems in canal and reservoir modernization, and allow the District to provide the large amount of flexibility growers are accustomed to.

INTRODUCTION AND BACKGROUND

The James Irrigation District (James ID, JID, or District) is located in western Fresno County in proximity to the cities of Mendota and San Joaquin. The District was organized in 1920 under the California Water Code. Currently the District consists of approximately 23,000 acres, and annually supplies from roughly 80,000 AF. In a normal year the District would receive 45,000 AF in surface water from the Central Valley Project (CVP). Of this 45,000 AF of CVP water, 9,700 AF is developed from the Districts historic right to San Joaquin River water (Schedule 2). The remainder of the

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grower demand is met by the 59 groundwater wells and unpredictable water supplies from the Kings River by way of the Fresno Slough Bypass. Provided below is a map of the District (**Figure 1**). The yellow area of **Figure 1** represents the boundary of the District, while the tan area represents to Eastside Well Field for which the District possesses groundwater rights.

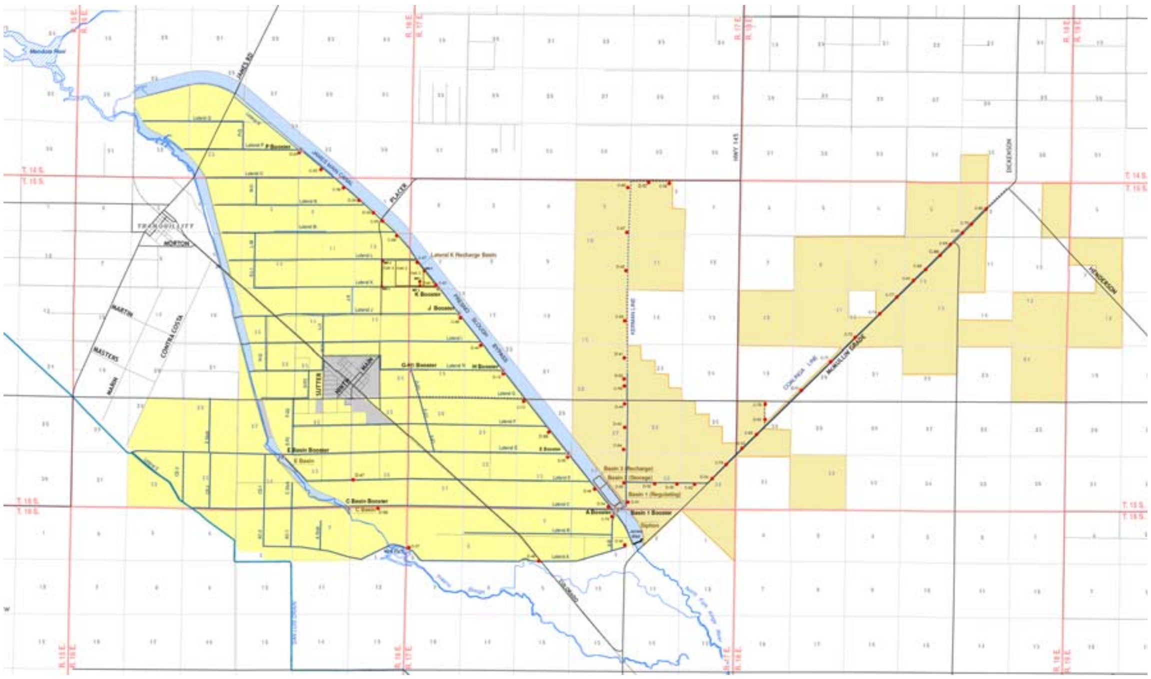

Figure 1. District Map

The CVP water is pumped from the Mendota Pool, whose backwater is adjacent to the eastern side of the northern quarter of the District. As the natural gradient of the District is south to north, the water received from the Mendota Pool must be pumped in reverse flow to be delivered to the District's distribution system. The water in the Main Canal is checked at four points, Laterals E, H, J, and P. These checks are also the location of the reverse flow pumps.

Groundwater pumped from the Eastside Well Field flows by gravity down the Main Canal. Of the 59 wells owned by the District, 35 are located in the Eastside Well Field. This water is delivered to the Main Canal at its highest point, allowing water to gravity flow down the District's Main Canal.

Recently the District has been concerned on the reliability of their 35,300 AF surface water supply available through the Central Valley Project. This concern is based upon water supply issues such as climate change, San Joaquin River restoration initiative, and pumping restrictions from the San Joaquin-Sacramento River Delta due to endangered species, foremost the Delta Smelt. These uncertainties have caused the District to reevaluate their water resources and determine if it would be possible to sustain their operations of providing agricultural water to users if the 35,300 AF of CVP water were not available.

ANALYSIS

To begin the analysis, the District measured daily system demand for the 2007 year (**Figure 2**). This was the most recent data and thought to be representative of a typical year by the District. To this data, the secured water sources (Schedule 2 and groundwater) were added (**Figure 3**). The District has a contract for 9,700 AF of Schedule 2 water, and has 59 groundwater wells. What was determined is that the District can acquire enough water from these two sources to sustain their practices, but cannot provide enough water to meet the instantaneous summer demand while maintaining the current level of grower flexibility.

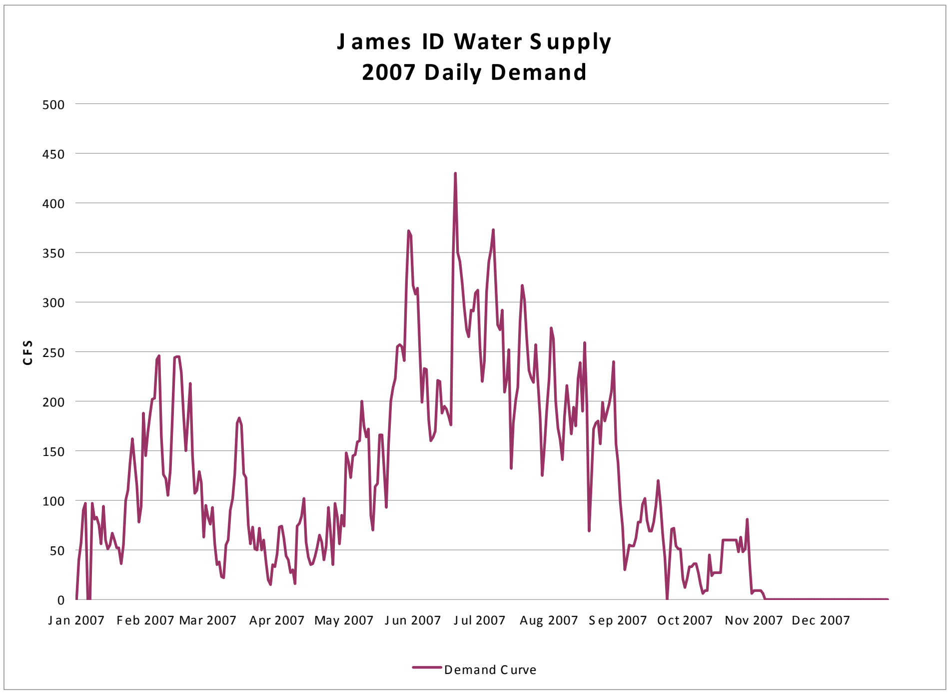

Figure 2. Daily Demand Representative of a Normal Year

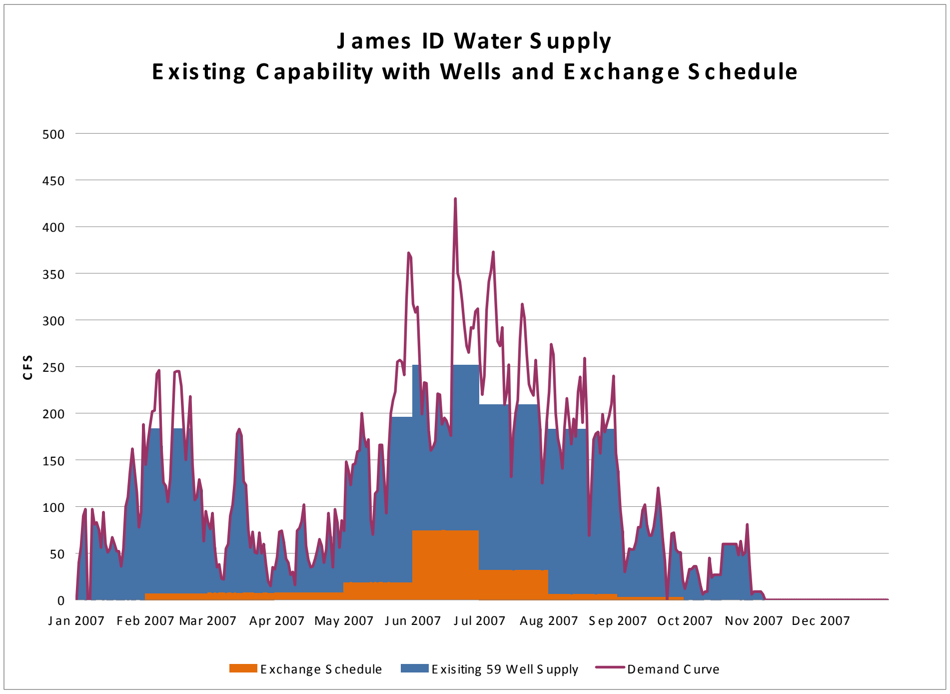

Figure 3. Secured Supply Inability to meet Current Demand

This left the District with one of three options; 1) switch from an on-request delivery method to a rotation type delivery, 2) increase surface storage capabilities, or 3) drill new wells. The District's decision was a combination of the final two; additional storage and wells. Although switching delivery methods could have helped balance out high daily flow rate demands, the District still wanted to provide water to growers as requested.

The next step was to investigate locations for these new facilities. There were many sites to choose from, each with their own pros and cons. Some options included providing additional storage behind a dam, modifications to a recharge site, and purchasing bankrupted land in another District. It was ultimately determined that three existing basins near the head of the James ID Main Canal would be the most ideal site for obtaining additional storage. One basin was currently being used as storage and the other basins were only utilized when flood waters were available off of the Kings River. The advantage to using this site was its proximity to the James ID Main Canal. The Basins were adjacent to the Main Canal, and located at the most upstream end. The drawback however, was that these basins are separated from the Main Canal by the Fresno Slough Bypass Channel. Connection of these facilities requires the construction of siphon pipes to pass flow underneath the bypass channel to connect the basins and the Main Canal.

With an additional 16 wells the new storage and regulation site needed to store approximately 3,000 AF. Based on the timing of water needs and the ability of the storage basins to fill and refill, the amount of storage needed to meet all demands was reduced to 1, 500 AF.

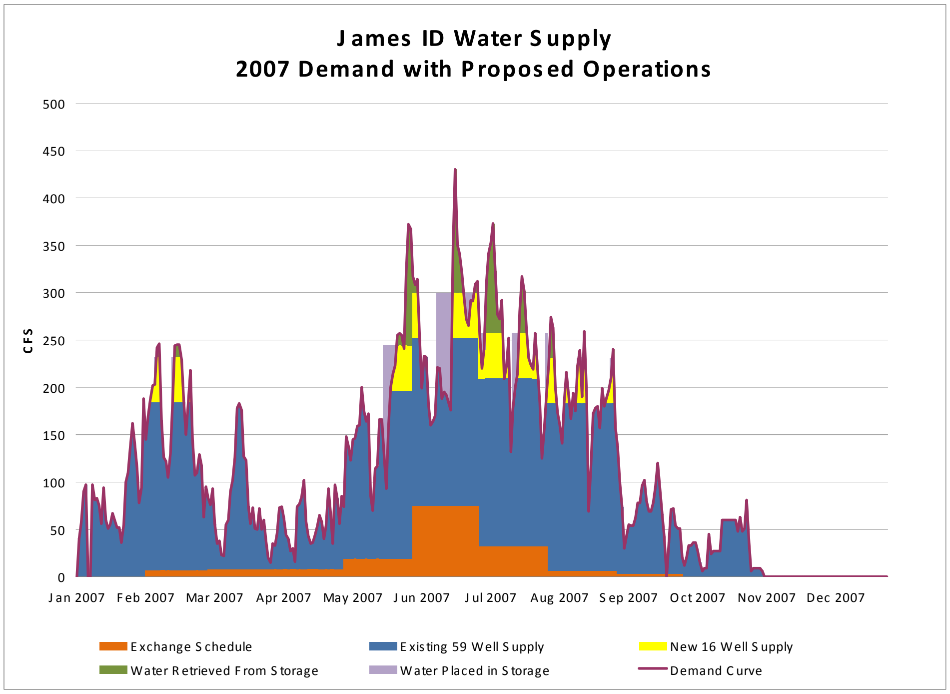

Figure 4. Future Operation of District

Figure 4 represents the planned operation of District facilities to meet system demand. From the graph in **Figure 4** it was also possible to interpret other necessary design information. The most significant design consideration is the maximum flow rates for filling and recovery. It was determined that 130 CFS could be required for recovery to the Main Canal. The other was how often these basins could be filled and the time it would take to fill them. Based off of the data from 2007, these basins are expected to be filled and refilled four times during the irrigation season.

PROPOSED DESIGN

<u>Fresno Slough Bypass</u>

Since the District had limited experience using automation, the goal of this project is to make this project operate as easily as possible with simple robust structures, while minimizing the amount of computerized controls required for operation. This is not to say it will not be modernized, as it is proposed to include long crested weirs, ITRC Flap gates, a Langemann gate, some localized controls, and flow measurement devices.

Currently when CVP water is available and the District is pumping contract water from Mendota Pool, the District uses lift pumps to force water upstream into each pool of the Main Canal. Since this project is being done assuming an absence of CVP supply the operation of the Main Canal will reverse. In essence, the system is being reconfigured so that it can operate in either direction.

Once the proposed modifications are made, the Main Canal will operate as historically operated, flowing downhill as it did when its sole source was water from the Kings River.

The new basins will store excess water supply, and then discharge the stored water into this most upstream pool of the Main Canal.

The proposed operation of the off-channel storage facility consists of storing excess pumped groundwater from the Eastside Well Field. The supply will enter the most upstream pool, the “E-Pool”. The “E Pool” will be maintained by flow control. An automated flow control device will be operated at the E-Check Structure, where the ditchtender will have the ability of setting the flow rate to be maintained by the device.

When there is excess flow from the Eastside Well Field, the gate will close and force water through the siphon and into the basins. The design flow from the Eastside Well Field is 120 CFS. Flow into the siphon will be regulated by level control. When the gate closes, the water level will rise and spill over a level regulation structure in the Main Canal. It is proposed that this structure consist of both ITRC Flap Gates and a weir section.

Once the water passes through the siphon it will reach a distribution structure. It is proposed that this structure have the ability to deliver water to the different cells on a predetermined arrangement. Distribution of water will be determined by weir sill settings. Once Basin 3 fills to set level, enough head can then be built to spill water into Basin 2.

Retrieval of water will be in reverse order. Since Basin 2 is so large and flat, it is likely that this water would infiltrate or evaporate before it could be retrieved, if left for an extended period of time. This is why water will be retrieved from Basin 2 first. Retrieval of water will be accomplished by a pumping structure which will be plumbed to pull water from either basin, depending on the position of gates. It is intended that initially this control will be manual, but could be easily modified for automation in the future. If automated, the pumps would be operated off of level control in the Main Canal.

Water will be conveyed from the pump station into a separate pipeline and siphon that parallels the spill siphon and pipeline flowing toward the basins, and discharged into the Main Canal.

All work to be performed in the Fresno Slough Bypass is capitally intensive. For this reason, structures in the project will serve multiple purposes. The first example is the pump structure. This is plumbed into both basins so that water can be retrieved from either basin by the operation of a single gate. This will save the District from installing a pump structure in each basin that would be capable of supplying the needed flow. The second example is that the pump structure also acts as the delivery structure into Basin 2. Since the pump inlet needed to be set at the invert of the Basin 2, it was fairly easy to incorporate this to deliver flow back to the basin through this same pipeline. The third example is the regulation structure in the Main Canal. Both the outflow and inflow lines will be built into the same head wall. The fourth and final example is that the pipeline that normally conveys flow to the Main Canal can also be utilized to send flow to the basins in periods of extremely high flows.

Recharge area

To reach the required 1,500 AF of storage, the basins will need to be further excavated, and the excavated earth will become an issue. After a topographic survey, it was confirmed that the lands lying north of the storage basins were low enough to capture Main Canal spill and flood waters released from Pine Flat Lake via the Kings River. It was decided that the excavated earth of the basins could be used to construct levees in this area to maximize storage and provide areas for intentional recharge. It is proposed that four cells be constructed based on the fall of the land, each cell storing water to a depth of 2 to 3 feet. This will also increase the utility of this area. **Figure 5** illustrates the proposed facilities of the Fresno Slough Bypass.

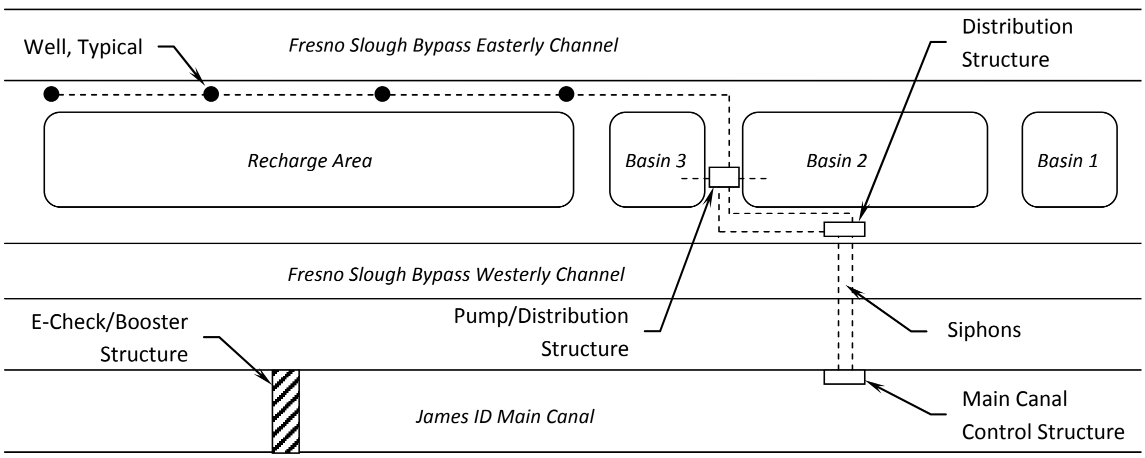

Figure 5. Overall Proposed Features in Fresno Slough Bypass Channel

Well locations

Well locations were based on many considerations. These included system limitations, water quality, and site availability. Overall, four locations were determined for well locations; 1) four in the Eastside Well Field, 2) four west of Colorado Ave, 3) four at the K Basin Recharge Facility, and 4) four at the proposed recharge facility (**Figure 6**).

Figure 6. Proposed Well Locations

The Eastside Well Field was chosen because the District has a right to pump water from this area at a flow rate of which they have not met yet; there was still enough available capacity to add the four wells. Another reason was that a utility company was installing a gas line through this area, causing the District to act quickly to get their needed infrastructure in place.

The area west of Colorado Avenue was chosen because of the fact that the District is limited to the amount of water that can be forced under the upstream highway. By placing wells here, more flexibility is provided to growers in this region.

The wells at K-Basin and the proposed recharge area in the Fresno Slough Bypass were chosen for the same reason; their location to a recharge facility. Water retrieved from here will be of better quality, require less energy to pump, and allow for banking opportunities in the future.

ENVIRONMENTAL AND CULTURAL ISSUES

With the majority of construction being in an environmentally friendly area, one of the first steps conducted by the District was a biological reconnaissance survey. Endangered species of note in this area consists of; San Joaquin Kit Fox, the Burrowing Owl, and the Fresno Kangaroo Rat. Once the survey was conducted, it was determined that the San Joaquin Kit Fox and the Burrowing Owl were present on site in the proposed recharge area. In addition to this, it was determined that wetlands existed on the site as well. Mitigation measures must be taken not to disturb any of these sensitive items.

Beyond the biological survey, a cultural survey was conducted as well. According to the database, the proposed site encompassed three artifact locations. Two of the three sites were found, and must also be mitigated for. Below (**Table 1**) is a summary of mitigation measures for both environmental and cultural issues.

Table 1. Summary of Issues with Mitigation Measures

Issue	**Mitigation Measure**
San Joaquin Kit Fox	Perform survey before construction, and check dens prior to flooding recharge area
Burrowing Owl	Cannot disturb during nesting period
Wetland	Replace any disturbed at a 3:1 ratio
Cultural Site	Cannot disturb with construction, but can flood site for groundwater recharge

Based on the California Environmental Quality Act (CEQA), environmental issues will be disclosed through the State Clearing House to obtain comments from agencies and other interested parties. It is proposed that a Mitigated Negative Declaration be used. Once circulated and comments are received, it is anticipated that numerous permits will be required. These permits consists of; the Army Corp 404 permit, the Department of Fish and Game 1600 Streambed Alteration Permit, and a Reclamation Board Encroachment Permit.

FUNDING

With the total cost of this project being nearly $10 million dollars, the District is searching for and utilizing grants and low interest loans to fund the construction. Thus far, the U.S. Bureau of Reclamation (USBR) has awarded to District $300,000 in their Water 2025 Challenge Grant Program, and is considering another $25,000 through the Water Conservation Field Services Program. In addition, funds from California Department of Water Resources (DWR) in the form of Local Groundwater Assistance Grants (AB303), and Proposition 82 loans will be used. **Table 2** provides a summary of present and future funding the District intends to pursue to fund portions of the overall project.

Table 2. Summary of Funding Opportunities Utilized by District

Funding Source	Project	Status
Water 2025 Challenge Grant	Turnout, Pipeline, Pumps and Basin Excavation	Awarded
Water Conservation Field Services Program Grant	Flow Control Gate at E-Check	Pending
Proposition 82 Loan	Well Construction and Equipping	Pending
Water for America Challenge Grant	Banking Expansion	Future
Local Groundwater Assistance Grant (AB303)	Well Location Investigation on Westside of District	Awarded

The grants alone have already provided nearly $400,000 to the project. While this is small compared to the overall cost, the District views the time applying for these grants as time well spent. The District plans to obtain the rest of the money for this project by increasing water rates and land assessments.

CURRENT STATUS AND CONCLUSION

As of early 2009, the project is making steady progress. Before the project can proceed much further, the funding issues must be resolved. James ID is in the process of outreach, educating growers, and getting feedback on the project. The CEQA process is being prepared, and is planned for circulation in the summer of 2009.

It is the goal of the District to start construction of the Fresno Slough Bypass Facilities next year. James Irrigation District anticipates that all facilities described in the proposed paper are operational prior to the 2011 irrigation season.

It is the opinion of the District that they are fortunate the water resources available to the District can be utilized to meet the irrigation demands of the District absent CVP supplies. By incorporating recharge facilities, the District can intentionally recharge flood waters so that mitigation of installing 16 new wells and the associated groundwater pumping is addressed. It should be noted that for long term sustainability, importation of surface supplies and CVP supplies is necessary. In this case it is expected that CVP supplies will be diverted only in wet years, and during drought years the system will be operated as described above.

ARVIN-EDISON WATER STORAGE DISTRICT SOUTH CANAL IMPROVEMENT PROJECT

Randy Hopkins, PE[1]

ABSTRACT

In the 1990's Arvin-Edison Water Storage District (A-E) developed a water management partnership with Metropolitan Water District of Southern California (MWD) in which A-E would "bank" excess surface water supplies for MWD. MWD is then able to call on A-E to return this banked water at a later date, typically during drought conditions. Over the past decade this program has proven to be successful for both A-E and MWD. Besides the water supply benefits of the program, MWD has received an unanticipated water quality benefit from the program. However, conveyance capacity limitations in A-E's South Canal have proven to be a bottleneck in the long-term effectiveness of the program for both partners.

In 2001, MWD secured $20 million in grant funding from the State of California to develop programs and projects which create a water quality benefit for MWD. MWD developed partnerships with various agencies and commissioned several studies to investigate various programs and projects to do so. In 2004 A-E, through a MWD funded partnership, commissioned a study to develop alternatives which would increase the capacity of the South Canal, and address the bottleneck in existing "forward flow" capacity. The study also investigated the feasibility of adding "reverse flow" capacity to the South Canal by utilizing gravity flows coming from A-E's turnout off of the California Aqueduct. Out of 18 programs and projects investigated, with various districts, MWD determined that A-E's South Canal Improvement Project (SCIP) was the only construction project which would provide water quality benefits to MWD and could be completed within the time-frame and budget of the grant funding.

In 2006, A-E and MWD worked to amend the existing program to subsequently store more MWD water in A-E and to allow A-E to return more water to MWD through the SCIP. This paper will discuss the analyses associated with increasing the forward and reverse flow capacities of the South Canal, various design considerations, project funding, scheduling, construction and constructability issues, and the operational benefits to both A-E and MWD.

INTRODUCTION AND BACKGROUND

For over 50 years, A-E has been very successful with conjunctive use of their surface and groundwater supplies by intentionally recharging water during wet periods (~1,500 acres) and recovering that water through their well fields in dry periods (76 total wells). A-E is uniquely situated in the southeastern portion of California's Central Valley. Their geographical location allows them access to the Friant-Kern Canal (their primary surface water source), Cross Valley Canal, Kern River, and California Aqueduct (as well as other

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river systems that connect to any of the above). Figure 1 shows the location of A-E in southeastern San Joaquin Valley. In addition A-E overlies alluvial fans which provide areas excellent for groundwater recharge and storage. This combination of ample access to surface water sources and the underlying geology made this area well suited for groundwater banking. This fact was recognized by MWD and led to the development of the first Water Management Program (Program) between the districts in the early 1990's..

A-E and MWD have have experienced substantial benefits from the Program for the last 15 years.. MWD has primarily benefited through their utilization of A-E's groundwater banking facilities to regulate their water supply between wet and dry years. In addition, MWD realized an unexpected benefit of receiving higher quality water from A-E as compared to their supply from the California Aqueduct. A-E has benefited from an infusion of funding from MWD which allowed expansion of existing recharge and extraction facilities, construction of new recharge and extraction facilities, and construction of the Intertie Pipeline and Pumping Plant (Intertie) which connected A-E's South Canal to the California Aqueduct. The program also requires MWD to deliver ten percent more surface water to A-E than is later returned. (MWD gets 90% back). However, conveyance capacity limitations in A-E's South Canal have proven to be a bottleneck in the long-term effectiveness of the program for both partners.

PROGRAM AND FUNDING

In 2001 MWD received a grant from the State of California for $20 Million. The grant funds were awarded to help MWD develop projects which would provide them with water quality benefits. MWD was required to use the funds by March 8, 2009 or risk losing any unspent funds. MWD entered into various partnerships with other agencies to find and develop these water quality projects. In 2004 A-E, through a MWD funded partnership, commissioned a study (discussed later) to develop alternatives which would increase the capacity of the South Canal, and address the bottleneck in existing "forward flow" capacity. The study also developed alternatives which would allow surface water to be brought into A-E through the Intertie and deliver to A-E water users and/or banked at the Tejon Spreading Grounds.

From the study, both MWD and A-E found there to be significant benefits to developing the SCIP. These included increasing the amount of water that could be returned to MWD in any year, and increasing the amount of water that could be delivered to A-E for banking through the Intertie in any year. Through subsequent analyses it was determined that the cost to bank water would be less if delivered through the Intertie instead of through the Cross Valley Canal and subsequently A-E's Forrest Frick Pumping Plant.

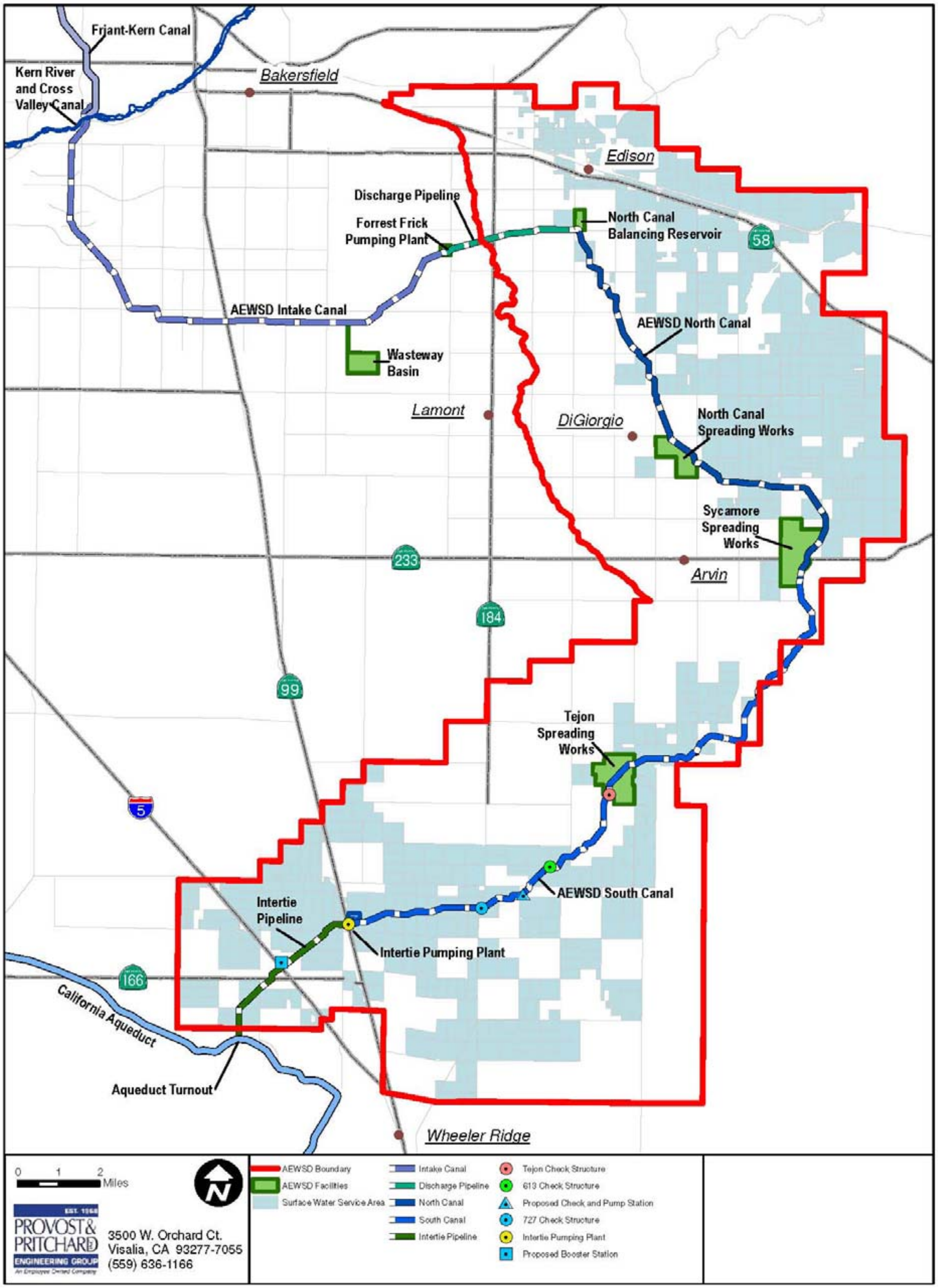


Figure 1. Map of Arvin-Edison Water Storage District

In 2006, after months of negotiations, the two districts developed the framework for the revised water management program agreement which allotted $16.16 Million of grant funds to the new program, provided for an additional $1.2 Million in funding from MWD, and up to $3.2 Million in funding from A-E. The agreement required A-E to build the SCIP in a manner which eliminated the bottleneck, and which also included a minimum amount of reverse flow capability. The agreement also stated that if A-E was not successful in completing the project prior to the grant deadline, A-E would be responsible to fund any shortfalls resulting from lost grant funds. The new program also created provisions where MWD could temporarily call on water from A-E to meet water quality needs, utilize the Program for dry year banking with less risk of lost water, and for A-E to better utilize the Program to balance their water supply and peak demand needs within a water year.

The bottleneck in the South Canal's forward flow capacity greatly restricted A-E's ability to return MWD's water quickly when called on, and A-E had sufficient capacity in its well fields to pump the banked water. Under certain provisions of the original program agreement, MWD was at risk of not being able to recover all of their available banked water before the program agreement ended in 2025. The desire for water quality benefits, constriction in return capacity, and the risk of losing a significant volume of banked water prompted MWD to consider how to help A-E increase their ability to return water.

PROJECT DEVELOPMENT

Capacity Study

Typically surface water is brought into A-E through their 15 mile Intake Canal and pumped through its Forrest Frick Pumping Plant and Pipeline to A-E's North Canal. A-E's canal system flows for an additional 30 miles to the south end of the District. A-E provides water to their growers through a number of canal-side pumping plants that deliver water through distribution systems under pressure to the growers. In a few instances, growers receive water directly from a canal turnout.

The area analyzed for the SCIP was the last nine miles of the South Canal from the Tejon Spreading Grounds to the end of the South Canal at the IPP (Figure 2). In this last section of the canal, the canal is divided into three reaches: the 613 Pool, 727 Pool, and IPP Pool. The original design capacity decreases significantly in each of the reaches from 500 cfs just upstream of the Tejon Spreading Grounds, down to 140 cfs in the IPP Pool at the tail end of the system.

An analysis of the historic operations and existing capacities was first performed to develop the alternatives to improve the South Canal. Eleven years of data from 1992 to 2002 was reviewed to determine how much water was delivered each month through each reach. The flows through each check were ranked to determine the probability of exceedence. Flow rates were developed for the 0% (maximum), 10% and 50% exceedence levels. Table 1 lists the results of this analysis.

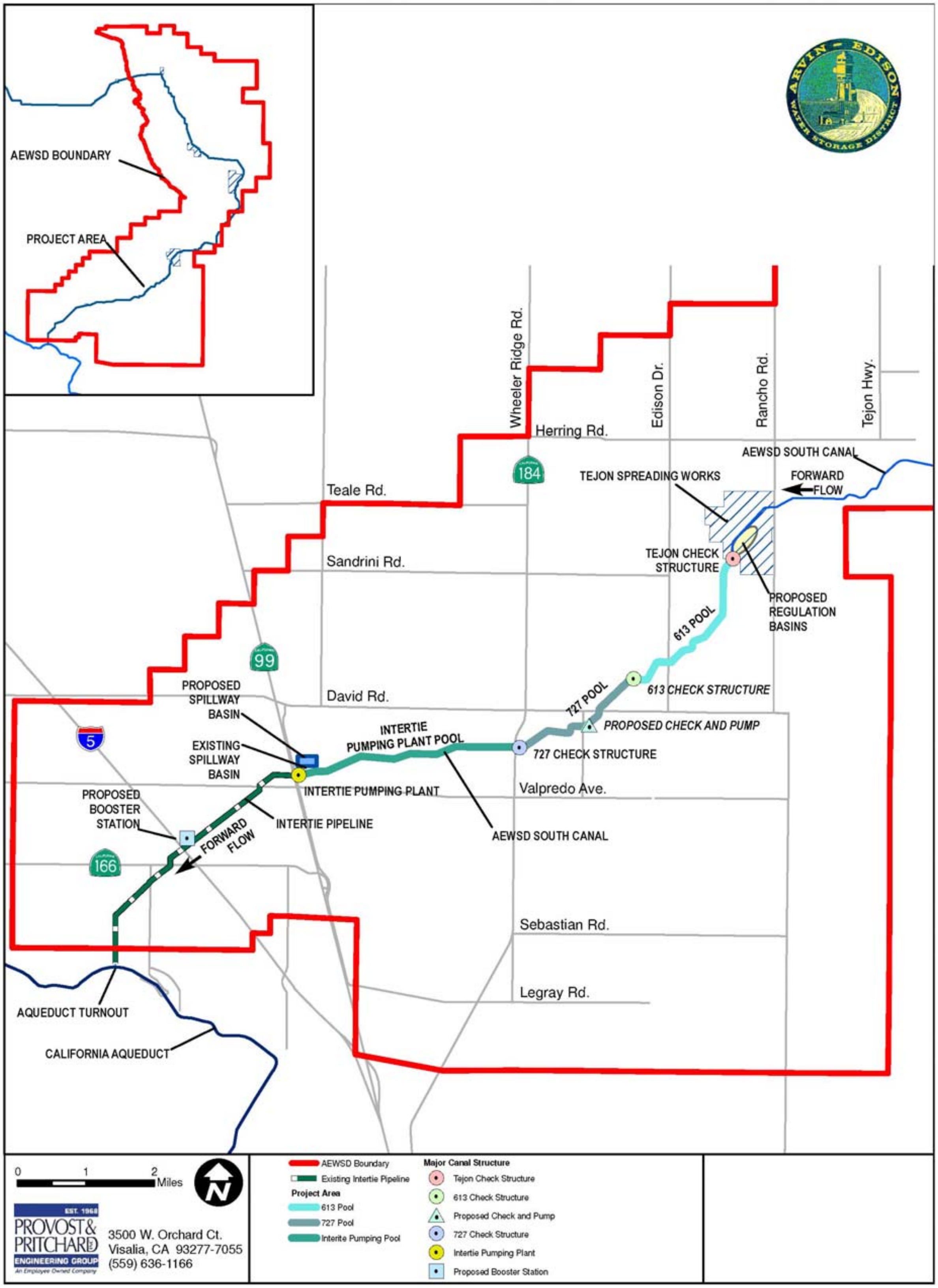


Figure 2. Project Area

Table 1. Percent Exceedence of Canal Flows for the 11-Year Data Period.

Percent Exceedence	Forward Flow Direction			Reverse Flow Direction		
	613 Pool (CFS)	727 Pool (CFS)	IPP Pool (CFS)	613 Pool (CFS)	727 Pool (CFS)	IPP Pool (CFS)
Maximum (0%)	190	153	100	48	92	190
10%	163	129	83	36	79	163
50%	71	53	30	18	42	71

From the flow data an average annual demand curve was developed and then compared to the information in Table 1. It was found that the average peak irrigation flow approximated the flows in the 10% exceedence level. Since the concept behind the project was to increase the long-term ability to return water to MWD, the 10% exceedence flows were used as the baseline for the analysis to meet irrigation demands in the peak month. Additional flows needed to meet deliveries to MWD were then added to these flowrates.

In addition to the demand analysis, an analysis of the existing canal capacity was performed. This analysis took into account the "as-built" information from the District's records and supplemented it with a minor amount of surveying of liner elevations and water levels. Using HEC-RAS, the capacity was determined to be slightly less than originally designed. The reverse flow capacity (from the tail end to the Tejon Spreading Grounds, assuming the addition of pumps at the northeast end of the reach) of each reach of the study area was also determined. Table 2 summarizes the maximum existing capacities of the South Canal in the reverse and forward flow directions.

Table 2. Summary of Existing Capacities.

Reach	Maximum Flowrate (CFS)	
	Reverse	Forward
613 Pool	47	330
727 Pool	61	225
IPP Pool	16	145

Note: A-E was able to reverse flow in the IPP pool only without pumpback structures. The 613 and 727 pools are rated based on the assumption that pumpbacks would be in place.

From the historic operations and existing capacity analyses, three forward flow and five reverse flow alternatives were developed.

Forward Flow. One of the main reasons for the SCIP was to increase the ability to convey banked water to MWD. Prior to the SCIP, the South Canal could convey about 140 cfs to the Intertie. The Intertie is able to handle approximately 175 cfs. Even with little or no irrigation demand, the South Canal simply could not maximize the Intertie. To address this shortfall, three alternatives were developed which included:

> F1: 22,000 AF/yr Increase. Each reach to have a minimum capacity equal to the Intertie capacity of 175 CFS;
>
> F2: 33,000 AF/yr Increase. Each reach to have a minimum capacity to meet irrigation demands plus meet Intertie capacity (175 cfs) 50% of the time; and
>
> F3: 51,000 AF/yr Increase. Each reach to have a minimum capacity to meet irrigation demands plus meet Intertie capacity (175 CFS) 90 percent of the time.

<u>Reverse Flow.</u> The ability to bring water in from the south end of the District from the California Aqueduct and conveyed to the Tejon Spreading Grounds was reviewed. These alternatives would give A-E the ability to serve growers with water from the Aqueduct as well as convey water to the Tejon Spreading Grounds for groundwater recharge. These alternatives would give A-E and MWD the ability to maximize the use of the Intertie in times when surplus water is available for banking or exchanges and at a cheaper rate (vs. CVC and FFPP). The alternatives investigated included:

> R1: 34,000 AF/yr Increase. Each of the three reaches to have a minimum capacity equal to the highest existing capacity of the three reaches (61 CFS);
>
> R2: 47,000 AF/yr Increase. Each reach to have enough capacity to meet the 90-percentile irrigation demands within the three reaches;
>
> R3: 63,000 AF/yr Increase. Each reach to be able to convey the maximum capacity of the Intertie capacity by gravity (127 CFS);
>
> R4: 90,000 AF/yr Increase. Each reach to be able to convey the maximum sustained recharge capacity of Tejon Spreading Facility (165 CFS); and
>
> R5: 98,000 AF/yr Increase. Each reach to be able to convey the maximum capacity of the Intertie capacity if pumping/booster facilities were added to the Intertie pipeline (175 CFS).

It should be noted that the AF/yr increases stated for each of the alternatives is a potential increase, based on a comparison of the historic data to proposed flow increases. For each alternative the increased delivery volume to the Intertie (forward direction) or to the Tejon Spreading Grounds (reverse direction) was tabulated for an entire year. The benefits from the forward alternatives are not added to the benefits from the reverse alternatives.

Because A-E operates the South Canal for 50 weeks each year, widening the canal was not an option. A parallel canal or pipeline was also eliminated as an option because of the high cost to build, operate and maintain a second parallel system. The only viable option to modify the canal was to raise the banks and concrete lining. Each of the forward flow and reverse flow alternatives were again hydraulically modeled (using

HEC-RAS) to determine how much the canal would need to be modified in order to handle the higher flows.

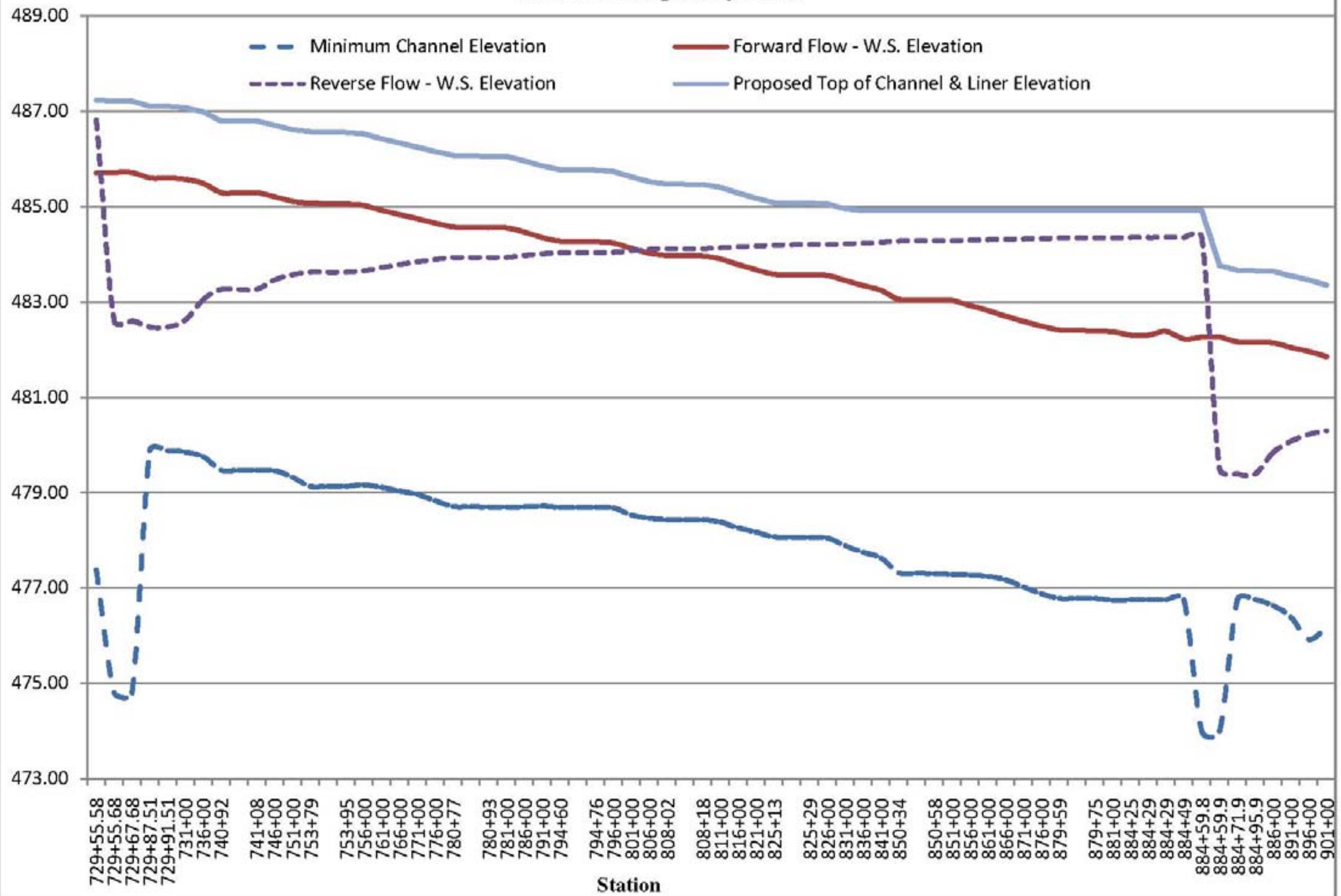
The results of the hydraulic models were then combined to develop fifteen project alternatives. To combine the reverse and forward alternatives, the maximum water level from either the reverse flow model or forward flow model was used as the high water level for the combination. An example hydraulic grade line for the F3-R3 alternative is shown in Figure 3. Quantities for new liner, structure modifications, earthwork quantities and required right of way developed for each of the fifteen alternatives and the associated costs were calculated.

Schedule

The study was completed in March 2006, but no preferred alternative had been selected. The task of selecting an alternative and committing to the project was done over a period of approximately 6 months. This involved additional operational analysis of selected alternatives, and the development of more detailed cost estimates. In consideration of the operational benefits and the costs, both A-E and MWD agreed to move forward with the F3-R3 alternative that combined forward option F3 with reverse option R3 (F3-R3 alternative). This preferred project had the potential to maximize the use of the Intertie in returning water to MWD 90% of the time and increase the ability to receive water from the California Aqueduct by 63,000 AF/yr, and could be designed and constructed within the available project funding.

The schedule for the project was aggressive. Starting in September 2006, the project design team began taking the SCIP from a studied concept towards completion. All of the work, including construction, needed to be done in time to meet the funding deadline of March 2009. This included obtaining final funding approvals, performing additional operational analyses, performing the environmental review process, surveying, permitting, geotechnical investigations, and engineering design. The construction phase of the project was allotted nine months. All of the other task deadlines were then developed backwards from the construction start milestone. These tasks were performed on carefully planned parallel tracks. This allowed the team to compress the timeline significantly, but not allow one task too far ahead of the others. The compressed time schedule required the SCIP's engineering, environmental, and administrative functions to be completed within about 1 ½ years of initiation.

Figure 3. Forward & Reverse Flow Elevations
Intertie and Spillway Pools



DESIGN AND CONSTRUCTION

Design

The design was initiated in September 2006 with the typical initial engineering investigations (geotechnical investigations, utility mapping, surveying, and schematic designs). Issues that needed to be addressed in the design were the location and configuration of new structures, equipment selection, level of automation, retrofitting of existing A-E facilities such as pump stations and laterals, coordination and approvals from the county roads department, and temporary facilities needed to operate A-E during construction.

Check Structures. The project required two of the three existing check structures to be replaced, an additional check to be added, and five new pump stations to be built. These facilities had to be built within an existing right of way and with minimal interruption to A-E's and adjacent farm operations' normal operations. During the preliminary design, final decisions had to be made on where these new check structures would be located and how they would be configured in order to build the temporary bypass channels. Various configurations and locations of the check structures and pump stations were considered. Ultimately through value engineering and schedule considerations, the check structures and pump stations at three of the sites were combined into one structure. This design minimized the structure footprint, which in turn minimized the size of the bypasses, the area taken for temporary easements, construction costs, and did not require any new permanent right of way acquisition. The new structures were located immediately downstream of the existing checks, allowing the District to continue operating normally during construction by way of "shoe-fly" facilities.

The new check structures were designed to be nearly identical. All were outfitted with the same size pumps and same size control gates. This served two purposes 1) the contractor could build three very similar structures thus reducing costs, and 2) the pumps and gates could be interchanged if needed in the future, simplifying future operations and maintenance. The fourth pump station at the Tejon Spreading Grounds was also designed to utilize the same pumps as the check structures in order to standardize around one type of pump.

Each of the check structures utilized two Langemann gates which have low power requirements, and can convey the flows needed and required less structural work to install. Other gates were considered, but were not used either because they could not be purchased in the size needed, or would require a substantial structure to be built to support the gate. Each pump station utilized two fixed speed pumps, and one variable speed pump to convey 130 cfs up the canal. During reverse flow operations the variable speed pump will allow A-E to adjust the flows to meet demands.

Controls. With the compressed time schedule, there was little time available to make decisions related to SCADA control algorithms and to develop the algorithms. The concept for automatic control of the canal in both the forward and reverse directions was developed, but never finalized. A-E will likely operate the canal to control water levels upstream of the checks in the forward direction. This will allow the fluctuations in flow to be passed downstream to the Spillway Basin located at the end of the canal. In reverse flow, the pumps will likely operate to control downstream level (discharge side of the pumps, upstream side of the gates). The goal of the reverse flow controls again being to convey fluctuations to the Spillway Basin.

Although the automated control was not a part of the SCIP, the backbone for a control system was installed. Each site included a PLC, radio, and sensors for upstream and downstream levels. The gates came equipped with position sensors. Information related to gate position, water levels, pump speeds, pump status are collected. The data is used to calculate flows for operator information at the sites and for use by A-E's watermaster in the office.

Spillway Basin. The SCIP will allow the full Intertie capacity of 175 cfs to be utilized and will increase the capacity of the last reach of the South Canal from 140 cfs to 260 cfs. The Intertie Pumping Plant, located at the Spillway Basin, is subject to periodic power outages. Because of this, the Spillway Basin at the end of the South Canal was required to be enlarged to create emergency capacity during a power outage. Expanding the basin would have created a hardship for the adjacent landowner, so the basin had to be deepened. This created its own set of problems and solutions.

About six to eight feet of soil had to be excavated from the Spillway Basin to create the required storage. This rendered the existing pump station useful over about only half of the depth of the basin. Subsequently a new pump station was designed and added to the basin. This soil excavated from the basin would then be used to raise the canal banks. However, the Spillway Basin is emptied about once every 10 years for maintenance, which meant that the soil at the bottom would be saturated at the beginning of construction. A-E decided it could balance the South Canal flows utilizing the Intertie while returning water to MWD. This temporary arrangement gave just enough time for the soils to dry out sufficiently for construction.

Bidding

The bid package for the full project was designed to give A-E the flexibility to award the contract in a number of ways. This was needed because the construction industry was just coming out of a time when prices had been rapidly increasing. The engineer's estimate prior to the bid showed that it was likely the full project could exceed the available funding. A base bid was developed which would meet the minimum requirements of the Agreement. Groups of alternative bid items were then added to the base bid which would allow more of the project to be built if the bids came in under budget. The first group of additive bid items would add the facilities required to meet the target flow requirements of the Agreement. The second group would allow the contractor to receive an additional week of shutdown time during the winter maintenance period if the cost reduction was sufficient. The third group would allow A-E to purchase spare parts and equipment, and add some additional features to the project.

Bidders were given five weeks to submit bids through a public bidding process. To keep the award criteria fair to the contractors and still give A-E the flexibility to award the contract as it needed to stay within budget; A-E stated they would award the contract in one of four ways. These were:

Base Bid
Base Bid + Group 1 Additive Items
Base Bid + Group 1 and Group 2 Additive Items; or
Base Bid + Group 1, Group 2, and Group 3 Additive Items

Five responsive bids were received for the SCIP; all were significantly lower than expected, falling within the project budget and leaving approximately $1.5 Million for contingencies and change orders. This led to A-E awarding a construction contract for the last option.

Construction & Constructability Issues

Construction started in late May 2008 and continued through the winter. Since the District had been operating their canal without the Spillway Basin at the end of the canal for a few months, the first order of work was to get a temporary basin on-line. The contractor was given 30 days to excavate the first quarter of the Spillway Basin to finished grade, place rip rap, build a temporary spillway, and close off the existing interior levee. Once complete, the District could again have a minimal amount of storage (about 30 AF) available to handle fluctuations at the tail of the system. This configuration in the Spillway Basin allowed the contractor to build the new pump station, excavate the remainder of the basin, and place the remaining riprap within the "dry" basin.

With water flowing in the canal for growers as well as return to MWD, the contractor accomplished much of the work. However, to complete the SCIP and re-align and tie-in the new facilities to existing canal alignment, the contractor needed the South Canal and lateral facilities emptied. The contractor was given weekends when A-E would shutdown the lateral systems, and a total of three weeks (during December 2008) for the entire South Canal to be shut down. During the three weeks when the entire South Canal was shutdown, the contractor was required to abandon the bypasses, regrade and build new concrete lining, complete a new headwall for 84 inch siphon, finish modifications to existing facilities, and put the new control gates into service.

Earthwork operations were underway during most of the construction. Extending the liner to match the existing canal section side slopes required over-excavation and recompaction operations to be done at the edge of the canal. With each equipment operation to prepare the canal lining subgrade, soil was spilled into the canal. The soil plugged filters on growers' micro-irrigation systems, caused premature wear on pump bearings and traveling water screen components, and filled the bottom of the South Canal. This might have been avoided using a benched cross-section, but would have cost substantially more money in additional concrete.

SUMMARY

The SCIP endeavored to expand a successful water management program between A-E and MWD and do so on an aggressive time frame in order to meet funding deadlines. In total nine miles of canal were modified, five lateral system headworks were modified, an existing basin enlarged, new structures built, and the basics of a new SCADA system installed. With the hard work, planning, and execution by the entire project team (owner, engineer, and contractor), the project was finished on time and within budget.

DESIGN AND PERFORMANCE GUIDE FOR NEW TECHNOLOGY IN IRRIGATION PIPE

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Tim Toliver, P.E.[2]

ABSTRACT

The state of our irrigation infrastructure is in a declining state of disrepair. Next generation materials and products are necessary to accommodate new demands for irrigation systems and meet long-term performance requirements. This paper will explain key features to be expected in the new irrigation and drainage technology. One of these features includes combining traditional pipe materials to form a composite pipe structure capable of exceeding the performance of single material products. This new technology is an intelligent design of steel reinforcement to control hoop stress and HDPE to create a corrosion barrier and attenuate transient pressure waves. Maintaining control of the transient pressure waves (or water hammer) related impulse load on the pipe, and associated irrigation system, reduces the initial system cost and extends the service life for the entire system. Test data that demonstrates the reduction in magnitude of these peak pressures as a result of this new technology will be presented.

Advancements in pipe jointing technology also utilizing a composite of materials will also be discussed. Additionally, potential failure modes of some pipe joints will be indentified.

In summary, research data will be presented that demonstrates the attenuation of peak loads on pipe joint and provide design guidance for a new generation of irrigation pipe. Additionally, the paper will present design guidance and design life predictions for irrigation and drainage pipe. This paper will benefit owners and engineers looking to increase the irrigation industry requirements for future irrigation projects.

INTRODUCTION

In many parts of North America gravity flow and low pressure irrigation systems were installed in the late 1950's and early 1960's. Many of these systems are nearing the end of their useful design life. Additionally, water is becoming a more precious commodity. Therefore engineers are being asked to choose a pipe system to service the agricultural irrigation system for the next century. This paper reports on several studies that were conducted to determine the service life and performance characteristics of a low head irrigation pipe intended to meet these long term design challenges.

Contech Construction Products has developed a pipe system which is designed to service gravity flow and low head pressure agricultural irrigation applications. This product

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called DuroMaxx is available in sizes ranging from 24-inches to 120-inches in diameter. This report explains testing that was conducted to determine performance characteristics and design life of this irrigation pipe.

This paper also describes the development of data to determine the pressure wave velocity for a new design for low head irrigation pipe. An example problem will demonstrate the expected surge pressure due to sudden change in velocity. Once the surge pressure is developed by the example problem, the impact of the surge pressure on the waterway wall and pipe joint will be analyzed.

BACKGROUND

The DuroMaxx pipe wall is a composite design of steel reinforcing ribs that are fully encased within the HDB rated HDPE profile. The steel reinforcing ribs provide the structural strength to resist the compressive or thrust loads from the backfill material. Additionally the steel ribs resist hoop or circumferential expansion due to internal hydrostatic pressure. The HDPE material forms the waterway wall and a protective barrier for the steel reinforcing ribs. Figure 1 below illustrates a cross section of the pipe wall.

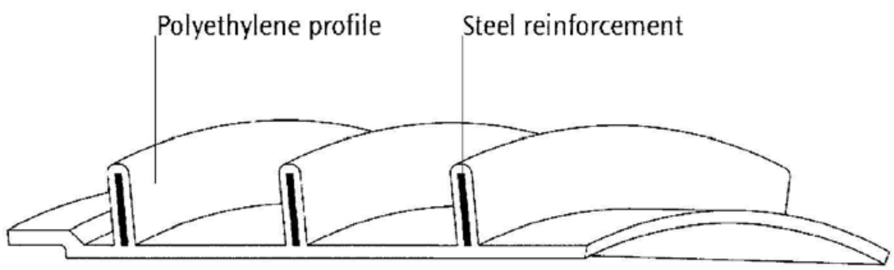


Figure 1. Cross Section of Pipe Wall

In addition to the use of steel reinforcing ribs, the bell and spigot of the pipe (i.e. pipe joint) is a composite that uses steel reinforcing bands. These steel reinforcing bands control dimensional tolerances of the joint when subjected to internal pressure. Figure 2 below illustrates a cross section drawing of the composite pipe joint.

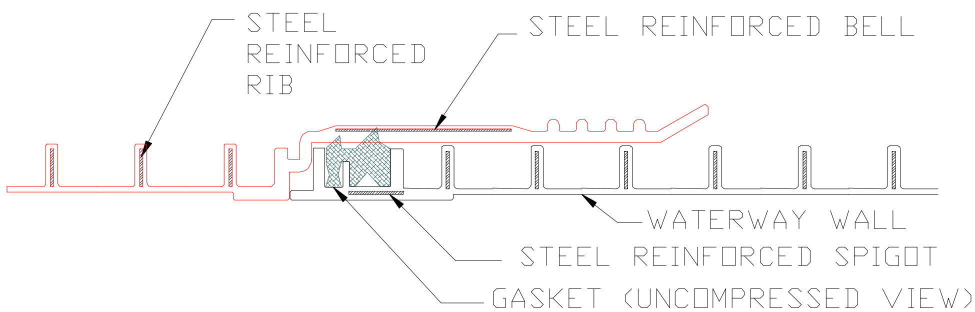


Figure 2. Pipe Joint Cross Section Drawing

The modulus of elasticity of HDPE is relatively low compared to other pipe materials. A typical short term modulus of elasticity for HDPE ranges from 110,000 psi and 150,000 psi. The modulus of elasticity of the steel reinforcement is approximately 29,500,000 psi. Both of these are traditional pipe materials; however the composite use of these materials is somewhat unique. Therefore it was necessary to conduct tests to determine the pressure wave velocity, long term performance and design life of this composite pipe system. Specific areas of interest for this pipe system study includes the impact the steel has on pressure wave velocity, the waterway wall response to pressure wave loading, and the bell and spigot response to the hydraulic loading.

Composite System's Impact on Pressure Wave Velocity

The HDPE's component of the pipe wall composite has a relatively low modulus of elasticity which has the effect of reducing the pressure wave velocity. The steel portion of the composite has a much higher modulus of elasticity which has the effect of increasing the transient pressure wave velocity. In order to determine the composite effect of these two materials on the pressure wave velocity, it was necessary to perform testing to measure the actual pressure wave velocity. Therefore full scale testing was performed to measure the pressure wave velocity of the composite pipe wall system.

To ensure the irrigation system is properly designed to handle the static pressure plus the transient pressure wave, it was necessary to determine the total pressure the system is likely to experience. The maximum transient surge pressure (also referred to as water hammer) is short-term pressure directly related to the pressure wave velocity within the pipe and is described by Equation one below.

$$P_s = \pm \frac{a * \Delta V}{2.31 * g}$$

$P_s = Transient\ Surge\ \mathrm{Pr}essure(psi)$

$a = Wave\ Velocity\ (ft/\sec)$

$\Delta V = Sudden\ Velocity\ Change\ (ft/\sec)$

$g = Gravitional\ Accerlation\ (32.2\ ft/\sec^2)$

(Equation 1)

There are a number of causes for pressure in an irrigation pipe system which may be experienced during normal operation. Terms critical to describing the types of pressures within the irrigation pipe system and used within this report are defined as follows:

1. Static Pressure (Long Term Pressure) – Maximum sustained long-term static pressure of a pipe system without consideration or inclusion of the transient surge pressures.
2. Working Pressure – Maximum allowable pressure within the system. The maximum working pressure is composed of the magnitude of the pressure rating plus maximum surge pressure.
3. Short-Term Pressure – Maximum short-term pressure is the sum of the magnitude of the static pressure plus the magnitude or the maximum transient surge pressure.
4. Transient Surge Pressure (Surge Pressure) – Short-term pressure as a result of a sudden change in velocity. This surge pressure does not include static pressure.

METHODOLOGY

Testing for the water hammer (or pressure wave velocity) and the pipe wall response to internal pressure were conducted on 24” diameter DuroMaxx pipe. Test results were used to verify analytical models. Analytical projections were then used to project larger diameter pipe response.

Pressure Wave Velocity

Testing was implemented to measure the pressure wave velocity. Figure 3 below is a schematic diagram illustrating the test fixture layout. Illustrated in Figure 3 is a five foot section of pipe orientated vertically, a 90 degree elbow and approximately 47 feet of pipe horizontally, which is instrumented and filled with water. The test fixture includes a steel pole orientated vertically, which guides a falling weight to the impact plate.

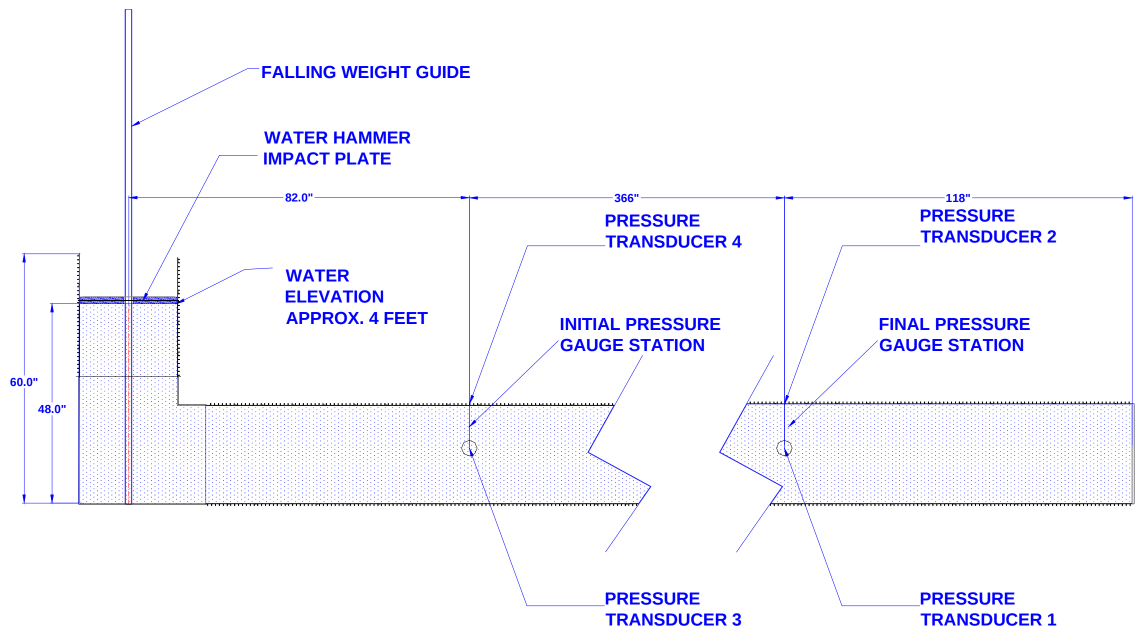


Figure 3. Schematic Diagram of Test Fixture

15 different tests were conducted by dropping specific weights onto a water hammer impact plate located at the water surface, which introduces a pressure wave into the system. This falling weight was dropped from five different elevations ranging from one foot to five feet in one foot increments. Additionally, the three different weights (i.e. 45 lbs, 65 lbs, and 85 lbs.) were dropped from each elevation. This variation in drop heights and weights generated a variety of pressure wave magnitudes.

Data collected from each of the 15 tests were measured by pressure transducers and captured by a data acquisition module. Pressure transducers were mounted at 4 locations along the length of the pipe. Two pressure transducers were mounted horizontally and two others were mounted vertically.

The initial pressure gauge station was located approximately 82” from the center of the elbow. At the initial gauge station a pressure transducer was mounted horizontally (gauge no. 3) and another was mounted vertically (gauge no. 4). Figure 4 illustrates the initial gauge station and pressure transducer no. 4, which was mounted vertically in the crown of the pipe. The final pressure gauge station was located 30.5 feet from the initial gauge station. At the final gauge station a pressure transducer was mounted horizontally (gauge no. 1) and a second was mounted vertically (gauge no. 2).

Pressure measurements were captured at a rate of 1,000 measurements per second. Separation distance between the pressure transducers and ends of the test segments were designed to minimize echo or “noise” from the translation of the pressure wave from end to end of the test fixture.

Figure 4. Pressure Transducer No. 4

Instrumentation for Data Acquisition. The data acquisition system and instrumentation was specified specifically for this project and is summarized as follows:

1. 1-MHz, 16-Bit, Data Acquisition Module
2. 4-solid state pressure transducers, max 30 psi, 0.25% accuracy
3. Omega linear 24 volt power supply
4. DaqView Software
5. Dell M20, 2 MHz, Laptop computer

The accuracy of the pressure transducers were checked with a known elevation or 'head" of water over the pressure transducer. Additionally, all instruments were certified as accurate by the supplier (Omega Engineering).

Pressure Wave Generation and Data Analysis. The pressure wave was generated by dropping a weight onto an impact plate on the water surface. The outside diameter of the impact plate was slightly less than the inside diameter of the DuroMaxx pipe. A rubber seal was placed between the edge of the impact plate and pipe waterway wall, which improved the energy transfer to generate the pressure wave. Prior to dropping the weight, the data acquisition began, which stored the data in an ASC II file. The ASC II data file was imported into an Excel spreadsheet. Figure 5 illustrates a typical complete data set for one test. It should be noted that Figure 5 illustrates the different initial pressures of each gauge.

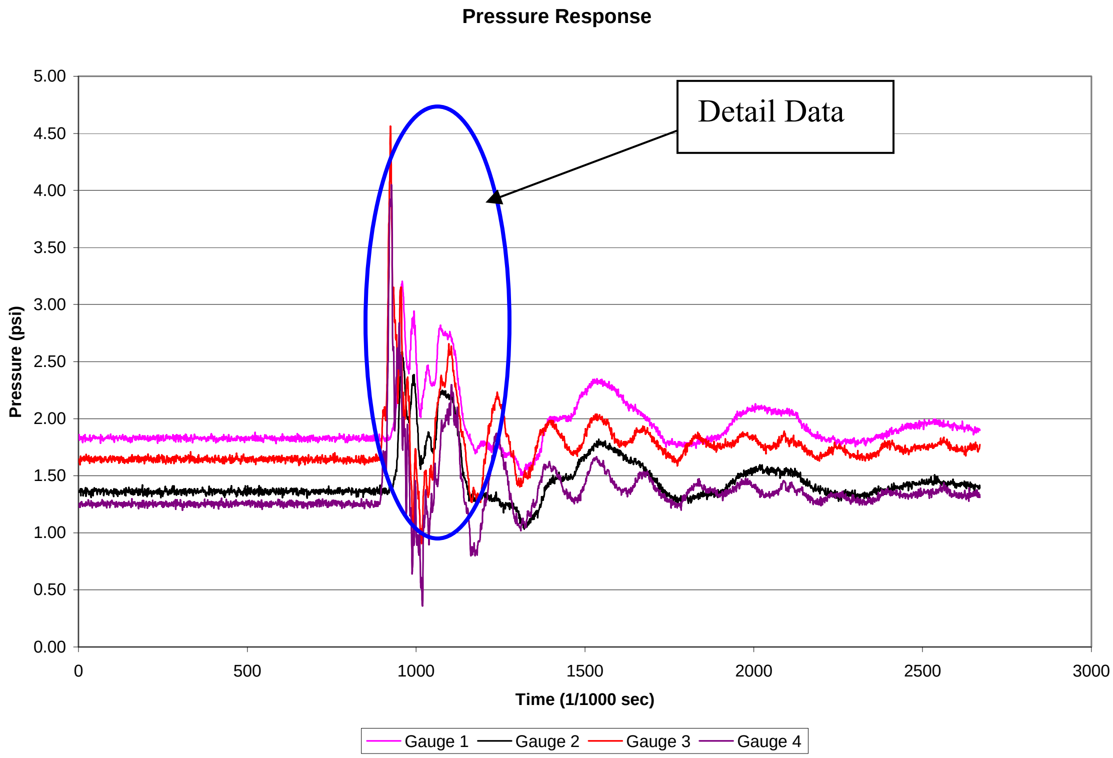


Figure 5. Plot of Typical Complete Data Set

Figure 5 includes data for multiple translations of the pressure wave within the 47 foot horizontal section of the test pipe. Once the data was collected, a plot of detailed data associated with the first pressure wave measurement for the initial and final pressure transducers was plotted. Identified in the Figure 5 plot is a region of detailed data, which is the detail data plotted in Figure 6. It is noted that each pressure transducer is located at different elevations. Therefore, the data has been shifted to normalize initial pressure for each pressure transducer. Once the initial pressure has been shifted and normalized, the detailed data was graphed as illustrated in Figure 6 below.

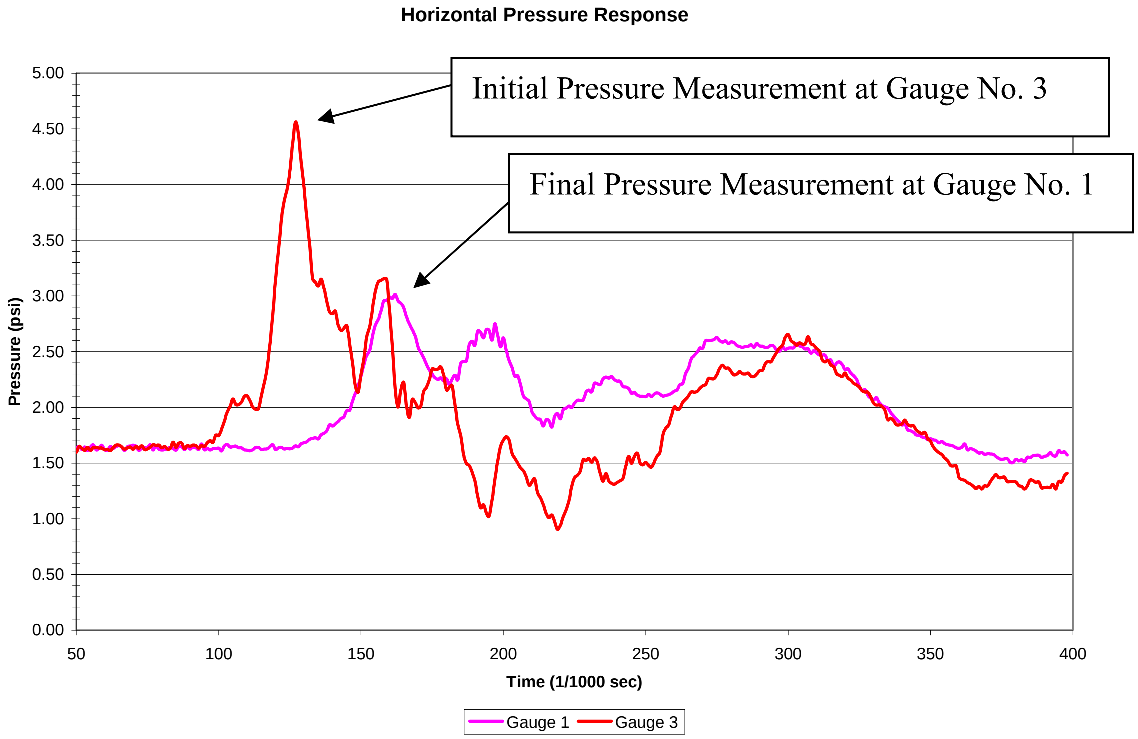


Figure 6. Plot of Typical Detailed Data Set

TEST RESULTS

Test results for the pressure wave velocity and the pipe waterway response to pressure are presented below.

Pressure Wave Velocity

Pressure and time data was captured during the testing. The distance between the initial pressure gauge station and the final pressure gauge station was 30.5 feet. The time between the peak pressure at the initial pressure gauge station and the final pressure gauge station was measured to the nearest 1/1000 second with the data acquisition system. The average velocity of the pressure wave was calculated using Eq (2) below.

$$V = \frac{\Delta D}{\Delta t}$$

$$Where:$$

$$\Delta D \equiv Change\,In\,Dis\tan ce\,(ft)$$

$$\Delta t \equiv Change\,In\,Time\,(\sec)$$

(Equation 2)

Based on the test data, the average measured velocity of the pressure wave is 919 ft/sec. Individual measurements for each of the 15 tests are shown in Table One below:

Table 1. Measured Velocity

Case #	Relative Time @ Gauge 3 (sec/1000)	Relative Time @ Gauge 1 (sec/1000)	Change in Time (sec/1000)	Distance between Gauges (feet)	Avg. Velocity (ft/sec)
1	198	231	33	30.5	924.2
2	71	104	33	30.5	924.2
3	127	162	35	30.5	871.4
4	71	107	36	30.5	847.2
5	66	98	32	30.5	953.1
6	128	160	32	30.5	953.1
7	217	251	34	30.5	897.1
8	134	167	33	30.5	924.2
9	86	118	32	30.5	953.1
10	60	93	33	30.5	924.2
11	130	161	31	30.5	983.9
12	63	97	34	30.5	897.1
13	107	139	32	30.5	953.1
14	150	182	32	30.5	953.1
5	54	91	37	30.5	824.3

The wave pressure is a function of the wave velocity as shown in Eq (1). Additionally, the wave velocity is a function of the stiffness of the pipe environment. Further the modulus of elasticity for the waterway wall influences the pipe's response during a pressure wave event. A comparison of wave velocity for different pipe materials is shown in Table Two below.

Table 2. Comparison of Transient Wave Velocities

Pipe Type	**Wave Velocity (ft/sec)**	**Modulus of elasticity for Waterway Wall (psi)**
Solid wall HDPE (DR 17)	836	150,000
DuroMaxx	**919**$^{(1)}$	**150,000**$^{(2)}$
PVC DR 18	1,303	400,000
Ductile Iron (CL 50)	3,981	24,000,000

Notes:
1. The wave velocity is slightly higher than a purely HDPE system as a result of the steel reinforcing ribs.
2. Modulus of elasticity does not include influence of steel reinforcement.

A comparison of the various pipe materials and the associated pressure wave velocity indicates the wave velocity of DuroMaxx is comparable to that of solid wall HDPE.

Furthermore, it is concluded that the HDPE portion of the waterway wall dominates the DuroMaxx response to internal transient pressure waves.

<u>Predicting Wave Velocity for Larger Diameters of DuroMaxx.</u> Testing performed in this study determined the pressure wave velocity for 24" DuroMaxx. DuroMaxx is presently available for sizes up to 60" in diameter. Ultimately DuroMaxx will be available up to 120 inch in diameter. This study addresses sizes up to 60-inch in diameter.

The velocity of the pressure wave is a function of the hoop stiffness of the pipe. The relationship between the pressure wave velocities may be expressed as shown in Eq (3).

$$a = \frac{4660}{\sqrt{1 + \left[K_{BULK} * K_s * \left(\frac{\left(\frac{D_{HDPE}}{t_{HDPE}} \right) - 2}{E_d} \right) \right]}}$$

$Where:$

$a = Wave\ Velocity\ (ft/\sec)$

$K_{BULK} = Bulk\ Modulus\ (water = 300{,}000\ psi)$

$E_D = Ins\tan\tan eous\ Modulus\ of\ HDPE\ (150{,}000\ psi)$

$D_{HDPE} = Outside\ Diameter\ of\ Waterway\ Wall\ (in)$

$t_{HDPE} = Thickness\ of\ HDPE\ (in)$

$K_S = Steel\ Stiffness\ Influence\ Coefficient$

(Equation 3)

Testing described in this report determined the velocity of a transient surge pressure wave for 24" diameter DuroMaxx pipe. Since all variables described in Eq (3) are known except the Steel Stiffness Influence Coefficient (Ks), it is necessary to algebraically solve Eq (3) for the steel stiffness influence coefficient. It is noted the steel stiffness influence coficient was developed specifically for this analysis. Eq (4) below reflects the steel stiffness influence coefficient as a function of known variables and may be solved for the steel stiffness influence coefficient (Ks).

$$K_S = \left(\left(\frac{4660}{a}\right)^2 - 1\right) * \left(\frac{E_d}{\left(\frac{D_{HDPE}}{t_{HDPE}}\right) - 2}\right) * \left(\frac{1}{K_{BULK}}\right)$$

$$\begin{aligned}
&Where: \\
&a = Wave\ Velocity = 919\ ft/\sec \\
&K_{BULK} = Bulk\ Modulus = 300{,}000\ psi \\
&E_D = Ins\tan\tan eous\ Modulus\ of\ HDPE\ (150{,}000\ psi) \\
&D_{HDPE} = Outside\ Diameter\ of\ Waterway Wall = 23.8 in \\
&t_{HDPE} = Thickness\ of\ HDPE = 0.068 in \\
&K_S = Steel\ Stiffness\ Influence Coefficient
\end{aligned}$$

(Equation 4)

Substituting known values into Eq (4) and solving as follows:

$$K_s = \left(\left(\frac{4660^2}{a}\right) - 1\right) * \left(\frac{150{,}000}{\left(\frac{23.8}{0.068}\right) - 2}\right) * \left(\frac{1}{300{,}000}\right) = 0.0358$$

Therefore:
K_s ≡ Steel Stiffness Influence Coefficient = 0.0358.

Since the wave velocity increases with higher pipe stiffness and 24" diameter pipe has the greatest stiffness of the DuroMaxx product offering, it is reasonable and conservative to use the 24" steel stiffness influence coefficient (Ks=0.0358) for all pipe diameters. Using Eq (3), the steel stiffness influence coefficient and the dimensions of the remaining diameters of DuroMaxx, the pressure wave velocities may be calculated. Based on the forgoing, the pressure wave velocity for the remaining diameters of DuroMaxx is shown in Table 3 below.

Table 3. Pressure Wave Velocity for DuroMaxx

Nominal Diameter (in)	Wave Velocity (ft/sec)
24	918.7
30	908.2
36	831.3
42	771.1
48	898.9
54	849.0
60	806.5

As shown in the Table Three the maximum wave velocity is 919 ft/sec and the minimum wave velocity is 807 ft/sec.

Dissipation of Wave Energy. Another outcome of the testing and analysis was that the pressure wave is dissipated relatively quickly within the DuroMaxx pipe. Tests show that the dissipation of the pressure wave varied from 20% to 41% of its magnitude over a distance of 30.5 feet. Detailed discussions regarding this data are outside of the scope of this paper, but are worthy of noting.

Design Guide for DuroMaxx in Irrigation Applications. A critical part of this study is to determine the appropriate operating parameters for the use of DuroMaxx in irrigation applications. Based on the pressure wave velocity test results, the HDPE material dominates the DuroMaxx response to transient pressure waves. The HDPE response to the pressure wave reduces the wave velocity thereby reducing the transient pressure wave magnitude. Specifically the viscoelastic characteristics of polyethylene enable DuroMaxx to safely withstand instantaneously applied transient surge pressures. Strain associated with these momentary pressure loads are proportional to the elastic response of the HDPE, which is relieved upon removal of the pressure load. The temporary elastic strain does not damage the polyethylene material and does not adversely affect the pipe's long-term strength provided the magnitude of the short term strain is within the short term strain capacity of the material.

EXAMPLE ANALYSIS

This section of the report runs through an example analysis and evaluates effect of projected pressures on the pipe waterway wall and pipe joint. Observations regarding the impact of the projected pressures are noted as well as distinguishing characteristics between the DuroMaxx pipe design and other non-composite pipe designs are noted.

Solve Example Problem

The following is an example analysis to determine the suitability of DuroMaxx.

Given:
24” DuroMaxx
Maximum Long term Static Pressure: 15 psi
Fluid Velocity: 2 ft/sec.
Maximum Working Pressure for 24” DuroMaxx = 45 psi

Determining the Transient Surge Pressure with Eq (1) shown below:

$$P_s = \pm \frac{a * \Delta V}{2.31 * g}$$

$$P_s = Transient\ Surge\ \mathrm{Pr}essure\,(psi)$$

$$a = WaveVelocity\,(919\ ft/\sec)$$

$$\Delta V = Sudden\ Velocity\ Change\,(2\ ft/\sec)$$

$$g = Gravitional\ Acceleration\,(32.2\ ft/\sec^2)$$

(Equation 1)

Solving Eq (1):

$$P_s = \pm \frac{a * \Delta V}{2.31 * g} = \frac{(919) * (2)}{(2.31) * (32.2)} = 25\,psi$$

Determining the Maximum Short Term Pressure for this application:
Maximum Short Term Pressure = Long term pressure + Surge pressure
Maximum short term pressure = 15 psi + 25 psi = 40 psi

Working Pressure Check:
Working pressure ≤ Maximum Short Term Pressure
45 psi ≥ 40 psi (therefore application ok)

Determining the Pipe Joint Response to 40 psi pressure.

As previously mentioned the DuroMaxx pipe joint is a composite pipe joint, which includes steel reinforcing in the bell and spigot. Pipe joints for the irrigation industry must maintain water tightness for long durations of internal pressure. ASTM D3212 describes a typical methodology for testing thermoplastic pipe joints. Pipe joints meeting this requirement are regularly promoted in the agricultural irrigation industry. This pipe joint test is a 10 minute laboratory test. In the case of thermoplastic pipe joints, the bell and/or spigot may creep over time when subjected to internal pressure or gasket compression load associated with the pipe joint assembly. Figure 7 below illustrates a non-reinforced HDPE pipe joint design, which may be subject to creep. Some manufacturers of HDPE pipe are beginning to reinforce the bell of the pipe but few are actually reinforcing the bell and spigot.

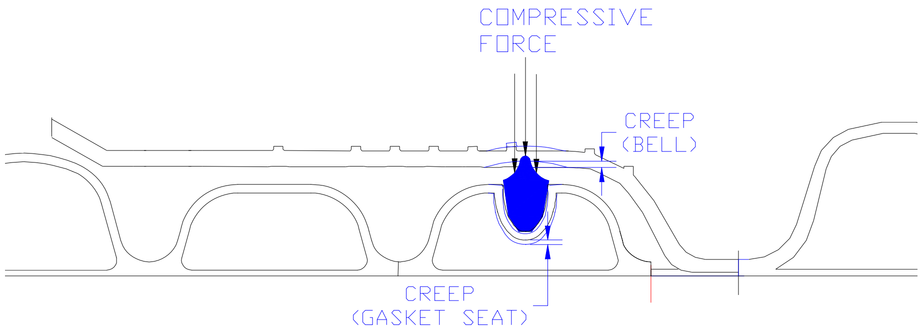


Figure 7. Non-reinforced HDPE Pipe Joint

A comparison between an unreinforced and reinforced bells and spigots are shown in Table 4 below. These values were derived analytically based on traditional strength of materials analysis. Assumptions for the analysis are shown as follows:

> Internal pressure = 15 psi
> Bell Inside Diameter = 25 inches
> Spigot Outside Diameter = 24.5 inches
> HDPE Bell Thickness = 0.2 inch
> HDPE Spigot Thickness
> Steel Reinforcement thickness = 0.04 inch
> Modulus of steel after one year service = 29,500,000 psi
> Modulus of HDPE after 10 minutes = 89,000 psi
> Modulus of HDPE after 1 year = 36,300 psi

Table 4. Performance comparison for reinforced and unreinforced pipe Joints

Bell inside diameter		
Time	Inside Diameter HDPE Bell (non reinforced)	Insider Diameter HDPE Bell (steel reinforced)
Initial bell inside diameter	25”	25”
After 10 minutes	25.26	25.004
After 1 year	25.65	25.004
Spigot outside diameter		
Time	Outside Diameter HDPE spigot (non reinforced)	Outside Diameter HDPE spigot (steel reinforced)
Initial spigot outside diameter	24.5”	24.5”
After 10 minutes	24.37	24.499
After 1 year	24.19	24.499

As shown above unrestrained HDPE goes through substantial deformation when subjected to constant internal hydraulic pressure for long periods of time. This change results in a loss of compression in the gasket and may result in a loss in the watertight seal at the joint.

In the case of the example where the DuroMaxx reinforced joint is subjected to 40 psi the bell inside diameter will increase by 0.01 inch to a new inside diameter of 25.01 inches. Where as the spigot will decrease in diameter by approximately 0.005 inch to a shortened outside diameter of 24.949 inch. These changes in diameter are well within the tolerance of the pipe joint and a watertight seal will be maintained.

Determining the Pipe Waterway Wall Response to 40 psi Pressure.

A second series of testing conducted during this study was to determine the pipe wall response as a function of the internal pressure. Of particular interest is the waterway wall response and required wall thickness to ensure a long term design life. Maximum allowable strain levels are well established for HDPE material. Therefore this portion of the study was conducted to ensure the wall thickness exceeded the minimum allowable.

This section describes the pipe wall response to internal pressure. As shown in figure 8 below the pipe wall will deflect when subjected to internal pressure. The pipe wall resists deformation through a combination of bending and membrane resistance. The waterway wall also resists sheer stress and hoop stress. However steel within the rib reduces the magnitude of hoop stress in the waterway wall. To determine the magnitude of stress within the pipe waterway wall the deflection of the pipe wall was measured as a function of pressure. The measurement was made at the midpoint between the reinforcing ribs (as shown in Figure 8).

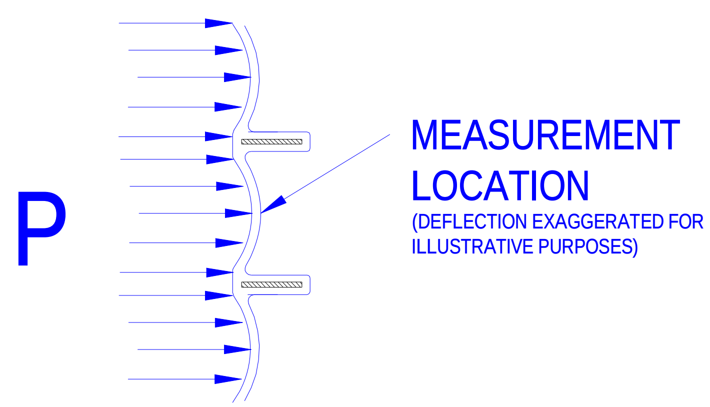


Figure 8. Pipe Wall Deflection

Pressure testing was performed on 24” diameter pipe with both ends plugged and subjected to internal water pressure. Once the pipe was subjected to internal pressure the response of the waterway wall was measured. Deflection measurements were measured by mounting a displacement transducer on the pipe. Additionally a pressure transducer was mounted in the pressure feed line. Pressure and displacement data was captured at rate of 1 measurement per second. The pressure was stepped up and displacement was measured at the acquisition rate of 1 measurement per second. Testing was performed above 30 psi for investigative proposes only. It is noted that the pressure transducer was rated for 30 psi. Therefore pressure measurements above 30 psi do not respond linearly to voltage and are not considered accurate. These values (above 30 psi) are shown for illustrative purposes only.

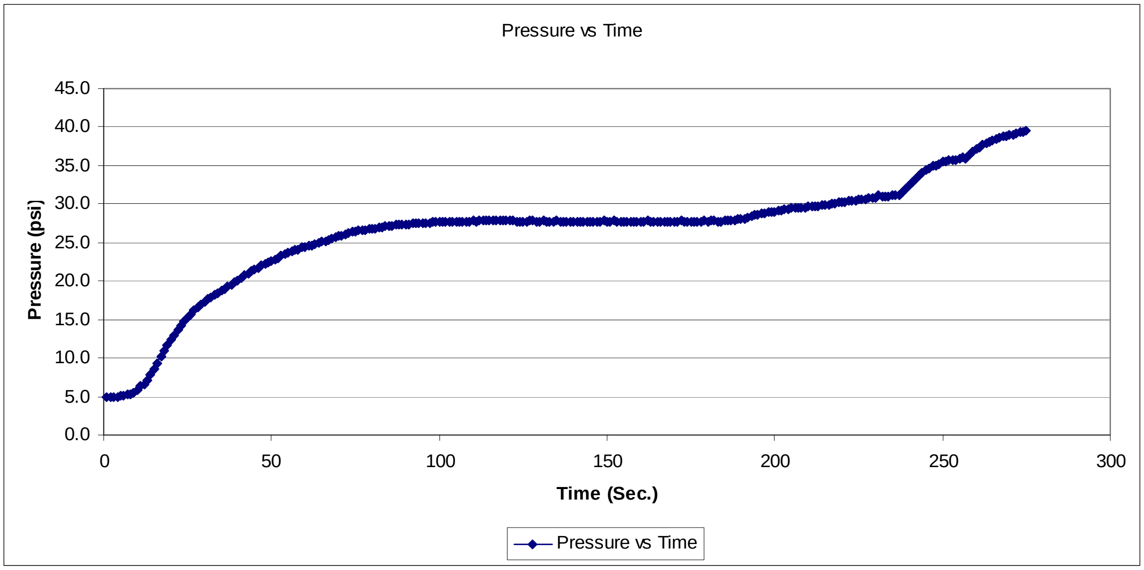


Figure 9. Pressure Application as a Function of Time

Instrumentation for Data Acquisition. The data acquisition system and instrumentation was specified specifically for this project and is summarized as follows:

1. 1-MHz, 16-Bit, Data Acquisition Module
2. 1-solid state pressure transducers, max 30 psi, 0.25% accuracy
3. 1- Linear Displacement Transducer, max 1 inch, 0.2% accuracy
4. Omega linear 24 volt power supply
5. DaqView Software
6. Dell M20, 2 MHz, Laptop computer

The accuracy of the pressure transducer and displacement transducer were checked with known elevation or ‘head” of water over the pressure transducer and a known displacement. Additionally, all instruments were certified as accurate by the supplier (Omega Engineering).

Waterway Wall Displacement vs. Pressure Data Analysis. The displacement of the waterway wall versus internal pressure was measured and is shown in Figure 10 below. The pipe was mounted in test fixture and subjected to internal pressure. Displacement of the waterway wall and internal pressure were measured with a data acquisitions system and stored the date in a excel spreadsheet. As shown in results graphed in Figure 10, at internal pressures of approximately 40 psi the waterway displacement of 0.054" was measured. This displacement represents a total strain of 3.2%, which is well within the allowable long term strain limit of 6.5%

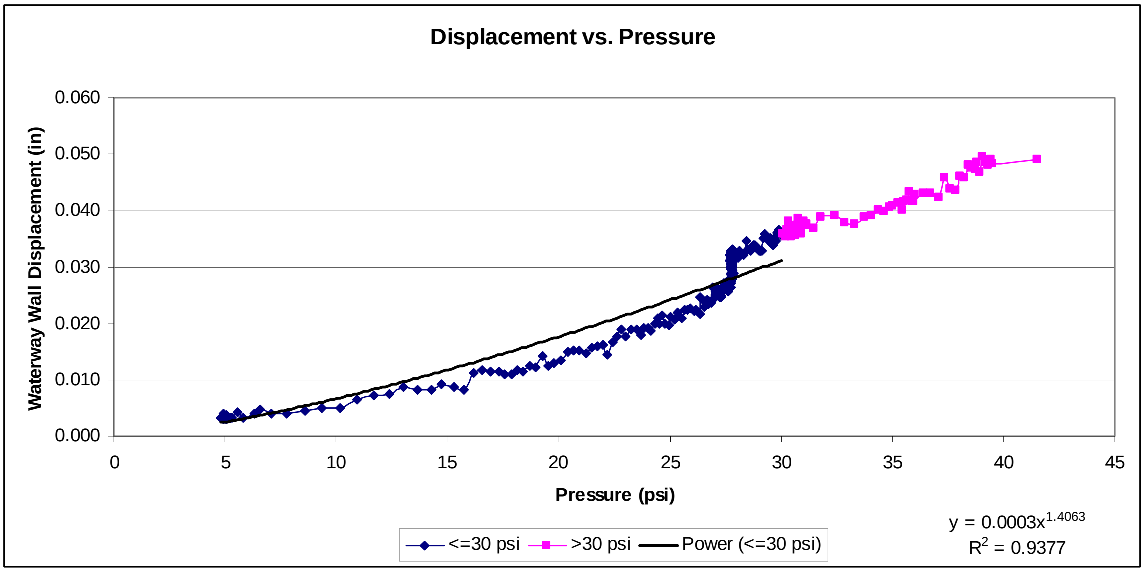
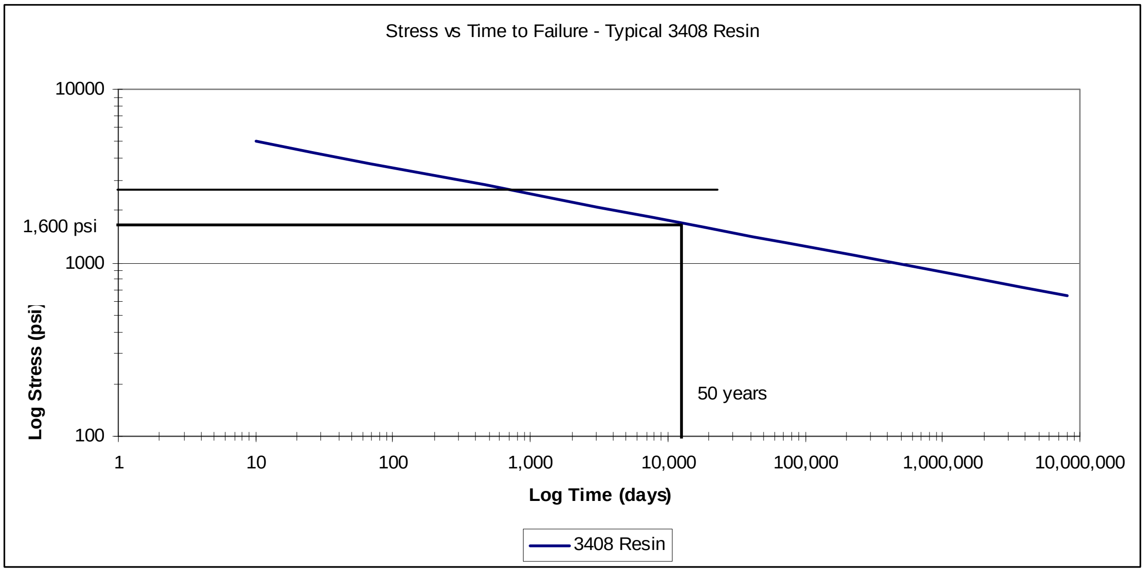


Figure 10. Waterway wall displacement vs. pressure

Response of Waterway Wall Related to Design Life. The long-term pressure rating for DuroMaxx is 15 psi of constant head pressure. As shown in Figure 10 this pressure corresponds to a waterway wall displacement of approximately 0.014 inch. This level of displacement represents a total strain at the midpoint between the ribs of 1.6% or a stress level of 360 psi. It is noted this HDPE has a design life of 50 years at a 1,600 psi stress level.

Figure 11 below illustrates a typical plot of stress vs. time to failure for HDPE. As can be seen at stress levels less than 1,000 psi the design life of the system are well over 100-years. It should be noted that this design life assumes there is no chemical failure of the HDPE such as antioxidant depletion. With that said the 50-year design life is well established for this class of HDPE and it is reasonable to expect the design life of the system to substantially exceed the recognized 50-year life. This design life assumption is especially true considering the service stress is approximately 22.5% of the design stress for 50 year service life.



Insert Figure 11. 3408 resin stress vs. time to failure

SUMMARY

DuroMaxx pipe is designed for the low pressure (15 psi and below) and gravity flow irrigation systems. 45 psi short term pressures due to transient pressure waves plus constant operating head pressure are within the design limits of the product. These allowable pressure ranges are a result of the pipe wall construction, which is a composite of two materials (Steel & HDPE) and the use of high stress capacity HDPE.

Due to the composite nature of the pipe wall it was necessary to perform full scale testing to determine the influence of steel on the pressure wave velocity. Testing on the pipe was performed and direct measurements of pressure wave velocities were made. Testing determined an average wave velocity of 919 ft/sec for the 15 replicates of testing performed. It was observed that the dissipation of the pressure wave ranges from 20% to 40% over 30.5 feet of pipe, depending upon the magnitude of the pressure wave.

Composite pipe joints have demonstrated the pipe design's ability to withstand long-term internal hydraulic pressure without experiencing a loss of sealing capacity. This loss of sealing capacity is demonstrated in analytical calculations comparing reinforced and non-reinforced HDPE pipe joint.

Testing on the waterway wall as a function of pressure indicates that strain levels 1.6% at the midpoint between the pipe ribs. These strain levels are well within in HDPE material's 6.5% long term strain capacity.

CONCLUSION

This study demonstrates that the HDPE constituent of the pipe dominates the pipe's response to transient pressure waves. For the 15 different measurements of pressure wave tests, the average velocity of pressure wave within DuroMaxx is 919 ft/sec. This pressure wave velocity is comparable to that of a HDPE pipe.

Pipe joints are capable of withstanding long term gasket compression and associated water tightness at 15 psi. Additionally the joint design is suitable short term pressure spikes of 45 psi without loss of sealing capacity.

The pipe's waterway wall is capable or withstanding long term internal pressure of 15 psi which represents 1.6% strain at the midpoint between the ribs, which is less than the maximum long term strain capacity of 6.5%.

The pipe's waterway wall is capable or withstanding short term internal pressure of 45 psi which represents 3.3% strain at the midpoint between the ribs, which is less than the maximum long term strain capacity of 6.5%

A design life of greater than 50-years is reasonable for 15-psi constant head and interment peak pressures of 45 psi.

PRACTICAL EXPERIENCE WITH STATE-OF-THE-ART TECHNOLOGIES IN SCADA SYSTEMS

Beau Freeman[1]
Charles Burt[2]

ABSTRACT

A Supervisory Control and Data Acquisition (SCADA) system is a powerful tool which, when implemented properly in irrigation districts, can lead to improved water delivery service to farms, more effective operations, reduced spill (and therefore reduced diversions), and in some cases a reduction in costs (less labor, less energy, etc.). However, widespread adoption of SCADA and automation technologies remains a technical and financial challenge for most irrigation districts. In spite of many good hardware and software products available on the market now, putting all the pieces together requires specialized expertise. Nevertheless, by following some straightforward strategies and rules of good practice, combined with advanced control techniques, even very complex automation systems have been successfully implemented. These implementation steps are briefly outlined with a focus on lessons learned. Updated implementation costs for typical system components are given to aid in project planning.

INTRODUCTION

This paper provides an overview of experience implementing SCADA systems. By investing in advanced communications and electronics technologies, agricultural water districts are striving to benefit from reduced operations costs, improved system performance, and increased responsiveness from a management standpoint. In practice, many engineers face challenges in each step of the project-cycle that mean achieving these benefits is far from automatic.

The California Polytechnic State University Irrigation Training and Research Center (ITRC) has worked with water districts in the western U.S. to put an increasing number of SCADA systems into operation. In this paper the authors relate recent experiences with implementation of SCADA and automation projects. The relevant lessons discussed in this paper can be summed up as follows:

- When beginning a project, explore whether a non-SCADA solution makes the most sense.
- Districts themselves can be the weak spot in a SCADA project, especially if they do not dedicate adequate budget and staff time.
- SCADA is different from typical engineering projects and involves special issues that affect the design, specification, and implementation of systems in districts.

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- ISaGRAF[3] has proved to be a valuable tool that benefits the entire SCADA team.
- The actual implementation costs for a "typical" SCADA site are anything but typical. However, the real costs for a site – if it is done properly – are much higher than most engineers realize.

KEEPING THINGS IN PERSPECTIVE – SIMPLE WATER CONTROL SOLUTIONS WITHOUT SCADA

SCADA systems are high-visibility projects within a water district because of their significant cost and, to a certain degree, the apparent 'magic' of the information technology involved. Indeed, the temptation of publicized SCADA technology is too much for some engineers to resist. At trade shows, in industry publications and during sales calls engineers are being exposed to advanced technologies that were unthinkable a decade ago. Unfortunately, this can lead to some expensive regrets when the same engineers try to implement them. In fact, the best solutions for improving water control often do not involve SCADA or PLC[4]-based automation.

The authors estimate that at present less than 5% of the existing canal control infrastructure (check gates and pumps) in California's agricultural water districts has some type of automation. At first glance this would seem to illustrate the very large potential for SCADA development in the future. Due to a variety of internal and external drivers, there will continue to be more SCADA projects in the coming years as districts invest in infrastructure upgrades. However, while ITRC provides technical assistance to perhaps 10-20 irrigation districts every year that are undertaking modernization efforts, only a few of these end up implementing a SCADA program, at least at first.

Solving water control problems in canal and pumping systems is a complex multi-disciplinary enterprise. Strategizing the proper control approach requires engineering expertise, ability to comprehend practical and complicated hydraulics, familiarity with modern water control designs, collection and analyses of relevant field data, and other knowledge gained through experience. When the proposed solution involves any type of PLC-based automation, the level of complexity increases by several orders of magnitude.

Still, we are extremely confident in the benefits of SCADA and ITRC has been involved with a large number of successful automation projects in the U.S. ITRC has a strong track record and has accumulated an unmatched expertise in implementation of canal automation. Enroute, we have also struggled at times and participated in some painful lessons dealing with SCADA and automation. Some of these lessons have been well-illustrated at previous USCID conferences (for examples refer to Norman and Khalsa, 2005; Perkins and Styles, 2007).

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[3] ISaGRAF is an industrial automation control software supporting IEC61131-3 PLC languages: Ladder Diagram (LD), Function Block Diagram (FBD), Sequential Function Chart (SFC), Structured Text (ST), and Instruction List (IL), plus Flow Chart (FC).
[4] Programmable Logic Controller

Fortunately, there are some practical solutions available such as the long-crested weir and ITRC flap gate, which both have well-deserved reputations. Both of these are automatic control structures, but neither one requires any SCADA at all (i.e., no electronics, no PLCs, no sensors, no programming, etc.). When a district's infrastructure is analyzed, we are always asking ourselves if a non-SCADA solution is possible. We only consider canal or pump automation when several prerequisite conditions are met (these conditions are outlined later in this paper). The reasons are simple – SCADA is expensive and can easily become problematic.

On the other hand, long-crested weirs are straightforward and have few problems. They are inherently safe structures, with few maintenance and labor requirements once they are in place. Of course, coming up with a good design requires experience and good judgment, and construction techniques can vary widely. For example, we have seen and designed long-crested weir structures that cost as low as several thousand dollars. But we are also aware of long-crested weirs in medium-size canals that approach $50,000 just for construction.

Figure 1. A long-crested weir being constructed with surplus K-rails (Banta-Carbona ID)

Of course, there are many, many control and monitoring situations where the physically simple solutions are impractical or too expensive.

PRACTICAL APPROACH TO MODERN SCADA FOR IRRIGATION DISTRICTS

Armed with some basic knowledge, districts have a better chance at getting a SCADA system that meets their performance objectives and stays within the allocated budget. The authors take for granted that it is (nearly) widely accepted now that SCADA systems should, among other things:

- Utilize only off-the-shelf, industrial-grade hardware
- Be provided by a qualified and experienced integrator
- Be commissioned with extensive hands-on training and thorough documentation

- Employ open architecture systems (i.e., it can easily be worked on in the future by another integrator)
- Have room for future expansion (scalability)

This section supplements some of these hard-learned lessons with new considerations.

Turning the Tables – What are a District's Obligations and Responsibilities?

In previous papers the authors have noted that the weak link in SCADA projects was typically the integrator (e.g., Piao and Burt, 2005). This can still be the case, although ITRC has worked successfully with a handful of integrators who had to meet pre-qualifications that ensure the selected firm has the track record, in-house technical expertise and sound financial health to support the project after it is finished. However, based on recent experience on some large canal automation projects, we have identified a new weak spot in SCADA projects that we did not initially suspect: the districts themselves.

The problem is not that districts lack expertise with SCADA. After all, this lack of in-house expertise is why districts hire consultants and integrators. It is unreasonable to expect most district engineers to fully understand all the ins and outs of successfully implementing a SCADA project. However, all districts will have had some experience with implementing at least some type of capital improvement project or infrastructure upgrades. In many ways, the steps in a SCADA project are similar to other "standard" engineering projects. Common steps include:

1. Identifying the problem, formulating options, and justifying the preferred solution
2. Preparing plans and cost estimates
3. Getting approval from management and the Board of Directors to proceed
4. Developing project specifications
5. Selecting vendors and engineering consultants
6. Finalizing design and specifications
7. Construction
8. Training and documentation

So what makes a SCADA project different? What special steps are involved? Enough examples are available now to expand upon both questions in detail. But what should happen <u>before</u> a district embarks on a SCADA project, before any significant planning or engineering is done? Is it possible to know in advance whether a SCADA project is likely to fail? If so, then consultants would be well-advised to steer a district away from SCADA as a solution for the time being.

Our experience has shown that it is worthwhile at the very beginning to focus on to what extent a district or other agency meets the conditions listed below. The authors are even considering ways to formalize these "pre-conditions" into some type of pre-project agreement that the district would have to sign before ITRC gets on board with them in a SCADA project. Our proposed SCADA pre-conditions include:

- A project manager. The district must appoint a project manager with sufficient authority to make decisions in a timely manner about budgets, schedules and commitments. The project manager has to be able to work across different departments (IT, engineering, administration, operations, etc.). The project manager must have a "can-do" attitude, construction experience, at least limited budget authority, and a willingness to learn new things.

- Sufficient budget to overcome the unexpected hurdles. Every SCADA project costs more than managers and the Board of Directors initially expect. With good planning and well-prepared specifications – not to mention hiring the right integrator – cost overruns can be minimized. But being reluctant to spend money when it is warranted can lead to even more problems down the road. The authors recommend that districts be prepared to budget an extra 10% to 20% beyond the initial project costs just to cover the inevitable unknowns.

- Commitment to be a team player. This is a sensitive area for obvious reasons. The district is ultimately the primary decision maker because they are the customer and the one paying for it all. Where the authors have run into trouble is when one or more of the following happens:

    - District staff from one department not sharing information with every member of the team (e.g., the classic problem of the left hand not knowing what the right hand is doing)
    - Districts being over-reliant on vendors and not checking with the consultants supposedly in charge of certain parts of the project prior to hardware or software selections being made.
    - District being reluctant or unwilling to direct sufficient resources to regular inter-action with the team. This is related to the budget issues mentioned above – meetings take up staff time and therefore cost money.

- Involvement of operations personnel. It is all too common for professional engineers to avoid involving the operations staff who will ultimately have to use the SCADA system. This is a common situation in irrigation districts, in which a gulf may exist between the engineers who dream up (from an operator's point of view) projects and the operators who have to live with the engineers' solutions. Operators should be involved in every step of the process. There is a huge learning curve and time is needed for acceptance; early buy-in and involvement is critical.

- Compliance with assigned tasks on a well-planned schedule. This is a difficult one to call a pre-condition per se, but there has to be a good understanding upfront by the district about how much is actually involved with supposedly simple tasks like furnishing and installing electrical conduit (plus all the day-to-day project management tasks involved with a SCADA project). Specific tasks are assigned between the district, the integrator and other consultants in the project specifications. Since there are always other projects already going on in a district at any one time – just consider how much regular maintenance is usually done in the off season when many SCADA installation tasks also take place – a well-planned schedule is essential.

Implementation Experience with ISaGRAF Control Software

Several years ago ITRC made a major shift in its approach to canal automation projects (see Piao and Burt (2005) for background about this decision). Prior to this ITRC had been handing over to integrators large, complicated (non-executable) flow charts of control logic. Integrators would then use the flow charts to create a ladder logic diagram for each PLC. This approach had several problems including a lack of understanding of canal control theory by integrators, susceptibility to programming bugs when the flow charts were converted into ladder logic, plus the fact that every new project had to basically start over with programming. As a result, ISaGRAF control software, consisting of six IEC 61131-3 programming languages in an integrated application environment, was selected by ITRC for PLC control programming.

Reasons that ITRC decided to use ISaGRAF included:

1. Cross-platform support among PLCs from different manufacturers
2. A clear line of responsibilities between ITRC and the integrator (i.e., the assigned PLC registers)
3. Compliance with international standards and open architecture
4. Ability to write control modules (e.g., upstream control with a radial gate, flow control with a sluice gate, etc.) that do not have to be rewritten for every job
5. Standardized programming interface, support for unlimited I/O, and sufficient flexibility for logic and arithmetic functions
6. Debugging features that aid examination of the code in simulation mode
7. Reasonable license fees

The authors' experience to-date with ISaGRAF has indeed validated most of the above reasons. As a result, the entire process of control logic development has become more efficient and reliable. Hassles and finger-pointing that used to occasionally arise when PLCs malfunctioned have been largely eliminated. Now ITRC handles all the PLC programming using an ISaGRAF approach that has been incrementally improved with each automation project.

Several issues have arisen, however, which merit discussion. First, ISaGRAF is not quite as universal as initially thought. This means that even though major PLC manufacturers (e.g., Allen-Bradley, Control Microsystems, Modicon, etc.) do provide ISaGRAF support, each one has its own customized libraries and extensions. In general ITRC does not utilize these manufacturer-specific features. However, there is still some extra programming that is required in order to take an ISaGRAF code programmed for one particular PLC and transfer it to a PLC from a different manufacturer. The ISaGRAF coding for the control logic is the same, but interaction with a particular manufacturer's firmware, communications ports, local displays, radios, etc. requires some special PLC-specific instructions also written in ISaGRAF. ITRC has not done a systematic evaluation of various manufacturers but our experience indicates that the time involved may vary from a few hours to a few days per PLC.

A second consideration is that very few integrators working in irrigation districts have any experience with ISaGRAF. It is likely this will change in the future as the popularity of ISaGRAF spreads due to its advantages (see the list above). On the one hand, since ITRC is responsible for the PLC programming there is no need for integrators to know about ISaGRAF. However, in practice some level of understanding of how the program works is required because of the teamwork nature of troubleshooting. It also matters because ISaGRAF opens up special possibilities for how the HMI can be used to interface with field sites.

One direct benefit of ITRC's approach using ISaGRAF is that the software kicks out the list of tag names and registers as part of the control programming. Therefore, an integrator knows what to bid on. However, this also means that ITRC has to develop the PLC code before the integrator is selected.

A minor consideration is the near universality of ladder logic. In large districts that have already implemented earlier generations of SCADA, there can be a hurdle involved with getting people to accept something they've never heard of. Usually, it is a matter of explaining the good reasons for using ISaGRAF. Furthermore, our approach means that it would be extremely rare for anyone at a district to ever need to edit a control program written in ISaGRAF (note: the same rule applies to the integrator as well).

Irrigation SCADA – Why Is It Different?

SCADA systems designed and installed for irrigation districts are different from other industries. While irrigation SCADA involves process control, there are some unique features. For a start, the "people" factor looms large. Already mentioned is the fact that districts lack in-house exposure to SCADA and trained technicians to operate and maintain a sophisticated computerized system. Often, operators in the field are being exposed to these technologies for the first time.

Another aspect of human organization is that fact that districts have to assemble a specialized team for SCADA projects. In other industries, large engineering and construction firms often view SCADA as simple – it's sort of an afterthought. However, in irrigation systems, designing a SCADA system first involves formulating a strategy for how water is going to be controlled and managed. Control options have to be weighed against objectives for improving water delivery service, conserving water, reducing energy costs, etc. This necessitates consultants dealing extensively with district staff from operations, engineering, administration, construction, and others. Then during implementation the district has to coordinate the work of various consultants, the integration firm, construction contractors (frequently multiple companies doing different parts of the job), as well as in-house electricians, construction/maintenance crews, etc. An experienced civil engineering firm that serves as a central coordinator for construction management can greatly benefit a district implementing a large project.

Other distinctive features of control systems for irrigation districts, such as lag-time, limit the involvement of integration firms who are used to industrial applications. In canal systems, things don't happen right away everywhere. For example, a change in flow rate made at a reservoir by remote control may not show up at another control point for several hours. Without proper tuning of the control algorithms based on hydraulic simulation modeling, resonance waves can be created (and get out of control) between automated gates. The selection of the correct control gate hardware, pump configuration, flow measurement device, etc. has to specific to each project and to control strategy being implemented. For these and other reasons, the required infrastructure and SCADA system have to be designed together, requiring consultants and integrators with specialized expertise.

CURRENT SCADA IMPLEMENTATION COSTS

A paradox: At the same time that the prices of the electronics hardware used in SCADA systems are going down – due to competition in the marketplace, cheaper components, newer models being brought out that target our industry, etc. – our cost estimates for a SCADA system are going up. What is the reason? Are SCADA systems really more affordable (or more expensive) than they were a few years ago?

Looking back at the proceedings from previous USCID conferences, one can find estimates for remote monitoring sites as low as a few thousand dollars. The authors would like to share some recent experiences that have convinced us the "typical" costs for a *properly-equipped* SCADA site are actually much higher than what was previously thought. For example, we used to tell districts that setting up a base station at their headquarters office would run around $30,000 to $50,000. Even then we would often get startled expressions from district staff members who were interested in SCADA but had no idea it would cost so much. Now, we will tell an interested district that they should count on spending at least $80,000 to $100,000 for a properly-equipped base station.

Part of the reason for rising costs is rising expectations. Districts are no longer satisfied (or won't be satisfied for very long) with just having one computer on somebody's desk that serves as the sole access point to the SCADA system. People want to be able to get into their SCADA systems from their homes, from laptops mounted in their service vehicles, and even from their smartphones while they are away. Managers and other office staff also want to have access to various summaries of the data on their own computers. This desire for 24/7 access by the whole organization comes with a significant cost. Computer server networks have to be set up with the necessary secure access, laptops have to be purchased and configured, extra software licenses have to be bought, etc.

Table 1 provides some updated cost estimates of various types of SCADA system components.

Table 1. Updated estimated SCADA system costs for irrigation districts (2009)

Item	SCADA*	Additional Construction Costs	Estimated Sub-total
Base station	$80,000-$100,000	---	$80,000-$100,000
Remote monitoring of a ultrasonic flow meter in a canal	$40,000	$20,000-$60,000‡	$60,000-$100,000
Automating a check structure with 2 radial gates for water level control	$70,000	$20,000-$50,000‡	$90,000-$120,000
Automating a pump station with a VFD controller†	$100,000	$50,000-$300,000‡	$150,000-$400,000

* Includes written specifications, SCADA hardware, control programming and testing, model simulation, HMI software, commissioning and documentation.
† Does not include new pumps
‡ Rough order of magnitude costs for enclosures, power service, infrastructure modifications

Another factor raising the cost of SCADA systems is that office computer networks are becoming more sophisticated and complicated – firewalls, web servers, antivirus software, continuous version updates, functional creep, etc. For example, ITRC is working with several districts that are implementing new billing software at the same time they are expanding their SCADA systems. Both efforts require extensive involvement of IT professionals because ultimately the systems have to run on the same office-wide computer systems. However, while it is tempting to think of one centralized database managing data from both the SCADA and billing systems, the IT costs involved, not to mention complexities, make it impractical. Therefore, the authors strongly recommend that as much as possible, different databases should not be integrated with each other.

Equipment costs bring up further issues. For automation projects in particular (versus for example just monitoring a single sensor for water levels), ITRC insists on only very high-quality industrially hardened equipment. It is possible to buy PLCs for only a few hundred dollars, but these are totally inadequate for running sophisticated automated control routines. The same rule applies to all the other components that go into a Remote Terminal Unit (RTU). It is a critical fact that a SCADA system is only as reliable as its weakest component. Does it make sense to spend thousands of dollars on a good PLC and then try to save a few dollars on a relay or switch? The answer is no.

In addition, early generations of SCADA systems may have consisted of a relatively simple RTU mounted on a pole. For newer systems districts usually require small buildings to securely house all the equipment, on-site interactive displays, etc. Many old systems had 15-minute query times with very simple control. Minimal information had to be transmitted to the office. Now, systems require high-speed transfer, storage and display of large amounts of data. This is especially useful for troubleshooting. A modern automated site can involve over a hundred PLC tags that interact with the office HMI.

Finally, another reason that the cost estimates in Table 1 are higher than what is typically published is that they include more than just the integrator's and consultant's bills. When one considers the amount of staff time that goes into working with consultants who help design the system, prepare specifications, collect field data, etc., the actual cost to the organization can be an additional one-third to one-half of what an integrator will charge for implementation. What about the costs to modify or replace older gate motors or demolishing existing but obsolete measurement equipment? In addition, for canal automation, surveying work is required, along with hydraulic simulation modeling, tuning the control algorithms, commissioning and field testing, etc. These costs all have to be put into the budget.

FUTURE TRENDS

SCADA systems will continue to evolve. Automation will be implemented with greater regularity as water districts transform themselves into modern service utilities. Here's a brief take on some likely future trends:

- A growing emphasis on security vulnerabilities
- Electronics getting smaller and smaller. For example, in the future, an electric motor may have a VFD controller built into its terminal box.
- Widespread use of wireless sensors
- Web-based interfaces and data access becoming the norm
- Mobile (remote) access
- Ethernet-enabled PLCs, radios and sensors (IP-based systems)
- Intelligence close(er) to the point of control. For example, some flow meters may eventually include built-in control algorithms to move a valve in order to control a flow rate, with supervision from the SCADA system.
- Integrated packages that combine PLCs, displays, radios, etc. into a single component
- Ultra-fast communications
- Smaller-scale SCADA systems at the farm level

SUMMARY

Experience to date with SCADA systems continues to prove there are significant benefits to irrigation districts that implement them. Risk of failure and costs can be minimized by following an approach that recognizes the distinctive features associated with SCADA implementation in irrigation districts. However, districts must be prepared to adequately fund a project and realize they have special obligations to make it succeed.

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COST-EFFECTIVE MONITORING AND CONTROL FOR IRRIGATION DISTRICTS

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Clinton Powell[2]

ABSTRACT

Today irrigation districts across the United States face mounting challenges to maintain viable operations as facilities age, competing demands for water increase, urbanization spreads, and competition for quality employees is becoming an increasing concern. Issues commonly dealt with by irrigation districts – including weather events, actions of livestock or wildlife, and unintended impacts of human activity – may be unchanged in likelihood of occurrence, but may now represent potential for dramatically increased financial impact compared with historical episodes of similar nature.

Access to real-time knowledge of conditions at key locations, and the capability to remotely operate or adjust operations of control structures at key points in the irrigation delivery system can enable an irrigation district to increase delivery efficiency and quality of service, enhance staff productivity, and respond rapidly and effectively to unexpected events. Supervisory Control and Data Acquisition (SCADA) systems that provide these capabilities are being integrated into the operation of growing numbers of irrigation districts.

In most situations, availability of external funding has played the pivotal role in the feasibility for irrigation districts to consider SCADA. Reclamation's Hydraulic Investigations and Research Laboratory, together with Reclamation's Nebraska-Kansas Area Office, are working to develop monitoring and control systems that could be adopted by districts of any size which can offer affordability within normal operating budgets (i.e. reasonable acquisition and installation costs, installation, operation and maintenance performed by irrigation district staffs with minimal need for on-site technical support).

This paper examines the on-going effort to develop and refine this concept through case studies of two demonstration projects in Nebraska.

INTRODUCTION AND BACKGROUND

Staff at Reclamation's Hydraulic Investigations and Laboratory Services (HILS) Group has been providing technical assistance to irrigation districts that are incorporating electronic monitoring and control capabilities in cooperation with Reclamation Area Offices. Frequently, the projects we have become involved with represent an initial

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venture by a district at utilization of electronic control and communication equipment as part of their daily operations.

A focus of system planning and equipment installation in these projects has been to seek to maximize the inputs from district staff. As might be anticipated, a degree of commonality has been observed with respect to some of the basic desired functions identified by districts. From the perspective of overall system capabilities and modes of system operations however, there tends to be numerous unique aspects and preferences developed by each district which are reflective of a district's operational history and/or of a district's perception of its in-house capabilities.

Against this backdrop of experiences, the HILS staff have adopted a strategy of working to develop systems which districts will largely be able to operate, maintain and even to expand themselves with limited need for outside consultants or integrators. On repeated occasions we have encountered situations whereby "turnkey" installations – developed and installed by others with limited input by district personnel – have been turned over to districts and have subsequently become marginally successful systems at best due to differing perceptions between the district and contractors. This paper employs a case study format to examine two projects recently undertaken by the HILS staff at the Ainsworth Irrigation District and at the Twin Loups Irrigation District in cooperation with Reclamation's Nebraska-Kansas Area office.

AINSWORTH IRRIGATION DISTRICT PROJECT

Project Initiation and Financial Assistance Structure

Ainsworth Irrigation District is located in north central Nebraska. Ainsworth's water source is Merritt Reservoir , located south of Valentine NE which impounds water from the Snake River and from Boardman Creek. Working with matching grant funding under Reclamation's Water Conservation Field Services Program, this project represents an initial step in incorporating electronic monitoring and control into the District's operations.

General Project Features

This project includes monitoring/control equipment installed at the head of each Airport Lateral and Sand Draw Lateral, the District's two uppermost lateral systems. At the head of each lateral, the initial feature installed was a ramp-type long-throated flume. Stilling wells were installed at each flume site.

<u>Airport Lateral</u> Work at the Airport lateral was begun following the 2006 irrigation season with installation of the long-throated flume (seen below in Figure 1).. In spring, 2007 a solar-charged radio/control unit was installed at the flume house which district staff had constructed over the flume stilling well. The districted opted to install hard-wired connections between the flume house control unit and the lateral control gates located approximately 70 yards upstream.

Figure 1. Airport Lateral Flume Site

A shop-fabricated “float and pulley” level sensor utilizing a 10K ohm 10-turn potentiometer as the sensing element was installed at the Airport Lateral stilling well. The potentiometer provides a 0-5 volt DC analog feedback signal to the radio/control unit.

Two side-by-side vertical slide gates control flow into the lateral. Adjacent to the gates, a second solar-charging system was installed along with an enclosure that housed gate relay equipment and the 12 volt battery that supplies energy for the gate motors. The existing hand-wheel operated gates were motorized by installing a chain-drive system. A sprocket was attached to the underneath side of each hand wheel. Gear Motors (12V DC) equipped with sprockets were mounted to the gate apparatus frame in line with the hand-wheel sprocket.

Retaining the hand wheel, as opposed to replacing it with a sprocket, was done in order to enable simplified reversion to hand operation in emergency situations. A shop-fabricated gate position indicator utilizing a nylon gear and a multi-turn potentiometer was installed such that the gear teeth are meshed with the gate stem threads. Limit switches at the Airport Lateral site are tripped by adjustable paddles affixed to an auxiliary rod that was attached to the gate leaf. The gear motor and chain drive system installed on the left gate of the Airport Lateral headworks is shown in Figure 2. Figure 3 shows a gate position indicator unit with the drive gear teeth meshed with the threads of the threaded gate shaft.

Figure 2. Chain Drive Gate Motorization

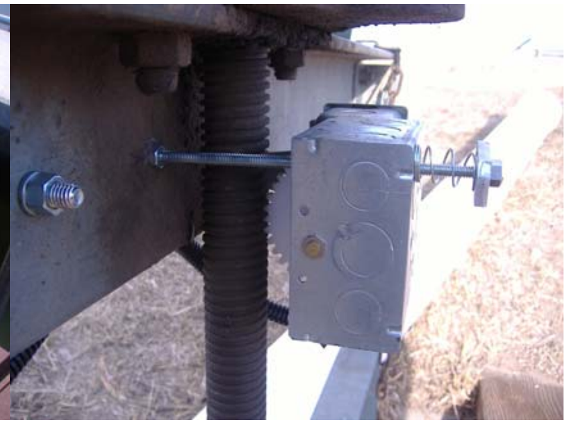

Figure 3. Shop-built Gate Position Sensor

A bank of toggle switches was installed at the enclosure housing the gate relays. A two-position on/on selector toggle enables operation either in “manual” or “auto”. From the “manual” setting, power is routed to two three position on/off/on toggle switches, each of which is wired to raise or lower one of the canal gates. In the “auto” position, power is routed to the output circuit of solid state relays controlled by digital output circuitry of the electronic controller in the flume house. Wires from the individual gate toggles as well as outputs from the solid state relays are routed to the gate limit switches. Wires returning from the gate limit switches are connected to the coils of mechanical relays that ultimately control energy to the gate motors.

The control unit installed at the Airport Lateral Flume site featured a built-in 5 watt radio unit operating in the 450-470 MHz range. A yagi antenna was installed on a mast attached to the exterior of the flume house. The approximate antenna height is 14 feet. At the Ainsworth office, and omni antenna was installed at a height approximately 20 feet above the ground and 4 feet above the eave of the office roof. Radio path between the Airport lateral which lies approximately 8 miles west of Ainsworth and the District office which is approximately a mile east of Ainsworth is gently rolling terrain. Radio path with the respective antenna heights was not line-of-sight.

<u>Office Base Configuration</u> Signal was routed from the office antenna to a base radio/control unit equipped with display and keypad located in the District’s “ditch rider room”. The base unit was also connected via RS 232 serial linkage to a PC unit in the District Board Room adjacent to the Ditch Rider Room. Access to equipment in either the ditch rider room or the board room was considered important since the business office/board room area is typically open only during regular business hours. The ditch riders have access to the ditch rider room at all times.

The radio/control units installed at both the Airport Lateral flume site and the office base unit are CD 100 models manufactured by Control Design Inc. of Placitas NM. The CD 100 installed at the field site is configured as a bracket mount unit designed for installation in an electrical enclosure in anticipation that enclosure size would be selected to enable housing various associated components on a site-specific basis. The CD 100 unit used for the office base is configured in a plastic enclosure intended for use either as a mobile unit or a wall-mount unit. Figure 4 shows the Ainsworth base unit in the ditch rider room.

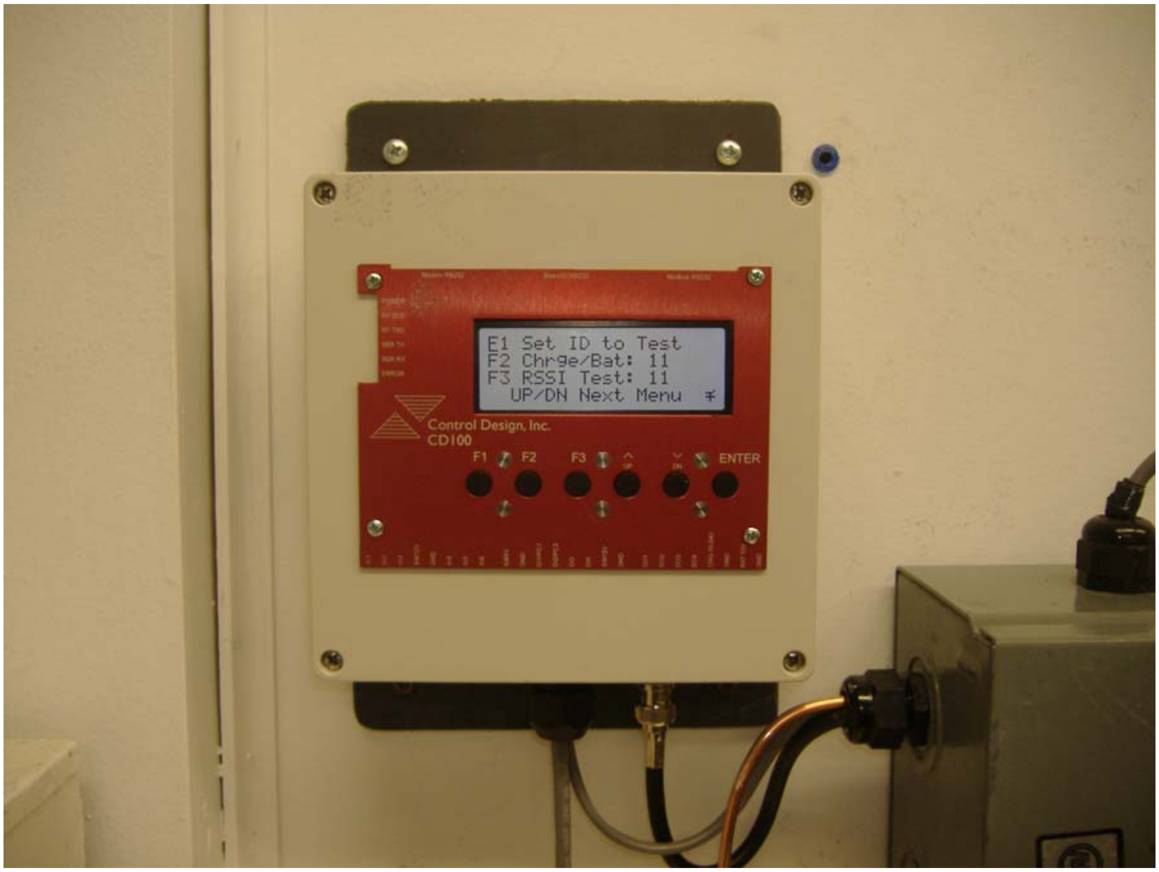

Figure 4. Ainsworth Base Radio/Control Unit in Ditch Rider Room

<u>2007 Ainsworth Project Operations</u> For the 2007 season, the District opted to operate using remote monitoring capability only. Gates at Airport Lateral were operated on-site using the toggle switches in "manual mode". A program was installed on the controller at the flume house to read water levels on 3 minute poll cycles and calculate flow across the flume. Updated flow level and discharge information, along with a time stamp were written to Modbus polling registers every poll cycle. This information could be read on-site on the field unit display screen or it could be accessed using the base unit in the Ditch Rider room by following on-screen prompts on the base unit display. Information could also be accessed from the linked PC. During the 2007 season, the Airport Lateral ditch rider was able to obtain flow condition updates via cell phone from anyone with access to either the business office or the ditch rider room.

<u>Sand Draw Lateral</u> Following the 2007 irrigation season, the district began work on construction of a second long-throated flume. The new flume was installed at the head of the Sand Draw Lateral. Like the Airport lateral site, a stilling well was installed in association with the flume and a flume house constructed over the stilling well. A shop-constructed float & pulley level sensor similar to the unit at Airport Lateral was installed

at the Sand Draw stilling well. A Control Design CD 100 radio/control unit, along with a solar charging system, were installed at the flume house.

The distance between flume and gates at Sand Draw lateral is similar to the layout at the Airport lateral. A county road crosses the path between the Sand Draw flume and the gate site. The complexity of dealing with a road crossing coupled with a significant increase in price of copper wire from the previous year were factors that led the District to opt for wireless communications between the gate and flume sites at Sand Draw. To accomplish this, the District constructed a second structure as a control equipment house adjacent to the canal gates and installed an additional CD 100 unit.

Similar to the Airport lateral, two vertical slide gates provide flow control at the head of the Sand Draw Lateral. These gates were fitted with chain drive equipment in the same manner utilized at Airport Lateral. The limit switch installation was altered slightly from the Airport Lateral configuration. Instead of attaching an auxiliary rod to the gate leaf, paddles were clamped to the threaded gate shaft at locations that do not impact the range of gate travel. Limit switches were installed at locations that aligned with the paddles. The gate position indicator installed was a shop built gear/potentiometer unit similar to the one described for Airport Lateral.

<u>2008 Ainsworth Project Operations</u> Flow control algorithms were installed on the gate control units at both Airport Lateral and Sand Draw Lateral at the outset of the 2008 irrigation season. A target discharge value (in ft^3/s) is entered into Modbus register 7065. As the program sees a measured flow rate that deviates from the target by more than a pre-determined “dead band” amount, a gate adjustment is called for. For the double gate system at each site, if an increase in flow is needed the program first looks to see which of the gates is lower (less open) then raises that gate a targeted distance. Conversely, for a decrease in flow, the gate which is higher will be operated for incremental closure in a given polling cycle.
Adjustment of the target flow rate may be accomplished in any of three ways. Following on-screen prompts using the on-board six-button keypad, a target rate may be entered on-site. Using the wall-mounted office base unit a user must first select the ID number of the field unit which is to be adjusted. Following a menu-driven process, a user then selects the “Change Target” option. Similar to the on-site process, the current target is displayed. After the value has been modified to the desired new target, on-screen displays direct a keystroke that triggers a radio transmission that writes the updated value to register 7065 on the field unit. The other alternative would be to use the Control Design software package from the PC linked to the base radio/control unit. The field unit ID # is entered, and register 7065 is selected, followed by a “read” command using a button in the software. Once the read command has successfully executed the current value will appear in a window in the software. The desired updated value may be entered in the window followed by a “write” command using a software button.

One glitch reported by the District during the 2008 season occurred during a period where one of the laterals was shut down for a few days following a rainstorm. The automation routine failed to shut gates completely in response to a “0” target value.

Subsequently the District is utilized the manual toggles for complete shut downs, pending a revision of the automation code.

TWIN LOUPS IRRIGATION DISTRICT PROJECT

Project Initiation and Financial Assistance Structure

Twin Loups Irrigation District is located in east central Nebraska. Its primary water source is Calamus Reservoir formed by impoundment behind Virginia Smith Dam on the Calamus River near Burwell NE. Twin Loups has previously established flow monitoring sites with telephone linkage that allows remote monitoring of flow conditions. In a problematic segment of the conveyance system, a less-than-successful previous effort was made to locally automate a short open channel reach of the 6.1 Lateral that feeds into a pipeline. Funding for the present project is broken into two aspects. Automation of the 6.1 lateral is needed to mitigate a design shortcoming. Reclamation is providing full funding for control upgrade of the 6.1 Lateral open channel reach. A remote-monitoring/remote-operating capability for flow control structures on the upper reach of the delivery system are financed under matching grant funding through Reclamation's Water Conservation Field Services Program.

General Project Features

Work on the Twin Loups modernization project was initiated in November, 2007 following seasonal shutdown of the canal system. The 6.1 Lateral consists of approximately one mile of open channel that conveys flow to the entrance of a pipeline. All field deliveries are from the piped section. There is no ability to spill supply/demand mismatch excesses along the open channel reach. Equipment previously installed by Reclamation featured radio/control equipment at each end of the open channel section with local communications only between the two sites. This system had not performed reliably, as evidenced by at least one overflow event resulting in costly damages.

The cost-share component of the project includes two check structures, along with the reservoir outlet works and the flume in the upper reach of the delivery system, all managed by the Dam Tender. The Dam Tender manages releases from Calamus reservoir, along with approximately 16 miles of conveyance reach including the uppermost delivery turnouts on the system. The Twin Loups Irrigation District – which was dedicated in 1986 – is a comparatively recently developed system. As the conveyance system was laid out, an agreement was made to share a reach approximately six miles long with the pre-existing Taylor-Ord Irrigation District. This shared reach lies upstream of the uppermost farmlands served by Twin Loups.

As operations have evolved, the shared reach has essentially become a buffer for the Taylor-Ord system, due in part to Twin Loups comparatively larger proportion of discharge along this reach. Taylor-Ord flow entering the shared reach typically fluctuates significantly, while releases from the shared reach into the lower part of Taylor-Ord's conveyance have minimal fluctuation. In order to manage unpredictable inflow/outflow mismatches from Taylor-Ord, the Twin Loups Dam Tender has typically needed to make multiple daily trips back and forth along his ride which represents a one-way distance of approximately 30 road miles from the lower end of his ride back to the dam outlet.

Targeted capabilities for the component of the project at the upper end of the Twin Loups system was remote real-time monitoring capability for all file sites plus the ability to remotely adjust the reservoir outlet as well as the two uppermost checks. For the project overall, targeted capabilities included real-time two-way communication with all field sites from either the office base or from mobile units. Brief descriptions of installations at each project site are as follows:

Office Base A Control Design Inc. CD 100 radio/control unit was installed at the District Office in Scotia NE. A yagi antenna was mounted on the District's voice communications radio tower. The base radio was installed on the west wall of the District shop adjacent to a communications radio unit. An alarm generating unit was also installed in the vicinity of the two radio units. Wiring installed between the radio/alarm installation and the office space on the east end of the building links the CD 100 via RS-232 serial connection to a PC, and links the alarm unit to the District phone system.

Repeater A repeater radio unit & antenna were installed at the District's Geranium voice radio repeater tower located approximately 20 miles north of the Scotia office. An omni antenna was installed at this site to accommodate radio traffic from multiple directions. Radio signal path tests had confirmed that all field sites for the current project, as well as the District office could communicate effectively with the Geranium repeater site.

6.1 Lateral Control Design Inc. CD 100 radio/control units were installed at each end of the open reach of the 6.1 lateral. At the lateral head, the CD 100 was connected to operate an existing 24V DC gate actuator with latching relay controls. As part of the project, the crest of a long throated flume at the site was raised to eliminate frequently observed problems with excessive submergence. A shop-made float and pulley level sensor was installed at the flume stilling well. Wiring was installed to link the sensor to the CD 100. At the pipe entrance end of the 6.1 lateral a submersible pressure transducer was installed near the pipe entrance transition.

Calamus Reservoir Outlet Flow from Calamus reservoir into the Twin Loups delivery system is controlled by two hydraulically operated gates using an electrically powered hydraulic pump. Pre-existing controls were manually operated hydraulic valves. To accommodate operation through the radio/control unit, the manual operator on the left valve was replaced with an electric operator. A CD 100 radio/control unit installed in the valve house was wired provide hydraulic pump start/stop capability in parallel with existing manual controls. Controls for the electric valve operator were wired through a selector switch that enabled local manual operation of the gate using momentary push button switches or fully electronic operation controlled by digital outputs from the CD 100. String potentiometers installed on both outlet gates provide feedback to the radio/control unit.

Wireless communications with a Parshall flume located approximately ½ mile downstream was accomplished with installation of a CD 100 unit and antenna at the flume. For level sensing, a 10K ohm 10-turn potentiometer was attached to the shaft of a shaft encoder float& pulley level sensor which the Natural Resources District had previously installed at the flume stilling well.

9.5 and 13.4 checks Each of the two checks featured nearly identical existing equipment and setup. Both checks consist of a single radial gate flanked by concrete overflow weirs that are angled inward in the downstream direction. At both checks, the gate winches are powered by AC powered electric motors with a latching relay contactor. The notable differentiating factor between the two sites is that the 13.4 check site has stilling wells for measurement of both upstream and downstream water levels, while there is only an upstream level stilling well at the 9.5 check site. Figure 5 is a view of the 13.4 check from downstream.

Figure 5. 13.4 Check Structure

Figure 6. Gate Shaft Monitor

CD 100 radio/control units were installed with yagi antennas at each check. For each site, existing two-way selector switches (run/off) were replaced with three way selectors (hand/off/auto) in the AC electric controls. Normally open relays operated by digital outputs of the radio/control units were wired in parallel with the “raise” and “lower” momentary button switches of the AC electric controls. A normally closed relay operated by a radio/control unit digital output was wired in series with the “stop” momentary button of the AC controls. Shop-fabricated float & pulley level sensors were installed at each stilling well. A PVC pipe was attached to the canal lining downstream of the 9.5 check for installation of a submersible pressure transducer to sense the downstream level. Gate position sensing was achieved by attaching 10K ohm 5-turn potentiometers to the gate winch shafts. Figure 6 shows this shaft monitoring potentiometer installation.

Mobile Radio/Control Units The Twin Loups project included two mobile radio/control “ditch rider” units. These units were configured with the same plastic enclosure used for the wall mount base-radio unit at the Ainsworth ditch rider room. The ditch rider units were configured with cigarette-lighter plugs and magnetic-base antennas to simplify transfer of the units from vehicle to vehicle or from vehicle to the ditch rider’s house.

One unit was provided to the Dam Tender and the other to the ditch rider whose ride included the 6.1 lateral.

2008 Twin Loups Operations Installation of equipment was on-going throughout the 2008 irrigation season at Twin Loups. The 6.1 lateral sites were the first locations brought into service. A program was installed at the 6.1 lateral gate to operate the gate to maintain a target discharge. At the pipe entrance site on the 6.1 lateral, a level monitoring program was installed in which the measured water level was recorded to a Modbus polling register each measurement cycle. From either the office base, or from a ditch rider mobile unit, both sites on the 6.1 lateral could be monitored remotely, and the target discharge at the gate site could be remotely adjusted.

Repeated difficulties were encountered in obtaining needed components for the electric operator for the hydraulic gate control valve at the reservoir outlet. This system was finally made operational late in the irrigation season. Equipment issues were also encountered with the 9.5 and 13.4 checks that prevented completion of installation tasks until after irrigation deliveries were shut down in September of 2008. All hardware is currently in place and functional and will be tested at t he startup of the 2009 season scheduled for late May.

Project Operational Goals

For the 6.1 lateral component of the project, algorithm modification for the pipe entrance location radio/control unit will utilize an observed water level change over a time interval along with channel geometry to calculate approximate discharge excess or deficiency. As the water level at the pipe entrance location is moves out of a “dead band” range the radio/control unit at the pipe entrance will be programmed to update the gate control target, based on the calculated discharge mismatch at the pipe entrance.

At times when, for what ever reason, water levels at the pipe entrance fall below/raise above predetermined minimum/maximum levels, the radio control unit at that site will generate and send out an alarm to the office base and to the mobile units. At the office, the base radio/control unit will be programmed to respond to an incoming alarm by keying up the alarm box it is connected to. The alarm box has been programmed to forward an alarm message through both the District voice radio system as well as to pre-selected phone numbers.

The District’s present objectives for the reservoir outlet and for the 9.5 and 13.4 checks is to remotely monitor conditions and to be able to remotely adjust flow control equipment at each site. For the reservoir outlet the radio/control unit at the Parshall flume will calculate the discharge rate at regular polling intervals. The radio/control unit at the flume will communicate with the unit at the reservoir outlet gate house and update the discharge rate stored in a Modbus polling register. When polled from a remote site, current vertical gate position of each gate as well as the current discharge rate may be obtained with a single inquiry. The Dam Tender will utilize this information to determine whether to make a gate change, and if so will determine a new target vertical gate opening. Using on-screen prompts and the six-button keypad on a mobile unit, an updated gate target may be wirelessly written to the reservoir outlet gate unit.

For the checks, programs have been installed on the radio/control units that monitor gate opening along with the upstream/downstream level differential to calculate discharge flowing under the gate, plus approximate flow rate over the weir walls. Upstream and downstream water levels, measured flow rate passing the check and current gate position values are written to Modbus polling registers in the on-site radio/control units to be available for query from the base or a mobile unit. This information will be utilized by the Dam Tender to identify any desired adjustment in target gate opening. As with the reservoir outlet, a new gate position target may be remotely entered for either check from a mobile unit or from the office base.

SUMMARY

Both the Ainsworth and the Twin Loups districts have opted to approach canal modernization with an incremental start. The features included in the in the initial project scope of each district could be readily assimilated into a broad-scope SCADA operation as the respective districts opt to expand their systems. A focus of Reclamation's involvement in each project was to seek to maximize the opportunities for use of "in house" resources irrigation districts could utilize in planning and installation of canal modernization equipment.

In follow-up efforts, Reclamation is working to provide training that will enable districts to develop a level of in-house capability with operations and trouble-shooting their systems to a degree that long-term operations can carried out in a cost effective manner with minimal need to hire specialist technicians to deal with equipment failures and system glitches that become a part of incorporation of electronic control and communications capability in a system. A training workshop held February 3-5 in Hot Springs SD was attended by personnel of Ainsworth and Twin Loups districts. (Also in attendance were personnel from irrigation districts from North Dakota, South Dakota, Colorado, and from the Republican River basin in southern Nebraska).

Costs of a modernization system can only be fully accounted for after multiple seasons of operation when issues unanticipated at the project outset can be looked back on in terms of staff time costs plus costs for equipment upgrades and replacements plus technical assistance that has been required. Up-front costs for systems installed at both Ainsworth and Twin are quite reasonable when compared with almost any projects of similar scope we are aware of. Neither Ainsworth nor Twin Loups has made any sacrifices in desired functionalities. To the contrary, some of the capabilities that are being developed as part of the Twin Loups system will be fairly unique. To the extent that these systems exhibit performance over time to the levels of reliability and functionality expected, the Ainsworth and Twin Loups projects will provide credence to the concept that incorporation of electronic control and communications equipment can be cost effective for a wide range of irrigation systems.

DISCLAIMER

No warranty is expressed or implied regarding the usefulness or completeness of the information contained in this paper. References to commercial products do not imply endorsement by the Bureau of Reclamation and may not be used for advertising or promotional purposes.

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DISCHARGE MEASUREMENTS IN IRRIGATION CANALS USING MULTI-FREQUENCY ACOUSTICS

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Victor Montano[2]
John Sloat[3]

ABSTRACT

The application of acoustic Doppler technology for water velocity measurements was initiated in the late 1970's as an oceanographic application and has evolved into a reliable standard for discharge measurements throughout the world. The increased demand and pricing for water resources has also created the demand for increased precision and accuracy for water users particularly in the irrigation industry. SonTek's Next Generation RiverSurveyor products, the S5 and M9, present end users with a new discharge measurement instrument that is easy to use yet highly robust in its data collection and processing. Typical discharge measurements with the S5 or M9 take only a fraction of the effort when compared to traditional gauging instruments. Multiple frequencies present users a high resolution velocity profile, as well as an extended bottom tracking range. Using the new system, the built-in echo-sounder and multiple frequencies allow the system two options to define cross-sectional area that are extremely accurately regardless of depth. The echo-sounder measures directly below the instrument to measure exact transect profile; this feature eliminates extrapolation errors of the traditional acoustic Doppler profilers by accurately defining discharge cross-sectional area, a key component when calculating discharge. The Next Generation RiverSurveyor has been used in irrigation districts in the Southwestern US, as well as throughout the world. Case studies will be presented analyzing a wide range of gauging scenarios, while highlighting the benefits of the technological advancement.

INTRODUCTION AND BACKGROUND

The use of hydroacoustic instruments to directly measure discharge in medium to shallow rivers and canals has been around for more than two decades. In the past, this technology was developed from instrumentation originally designed for oceanographic applications. Specialized software and floating platforms have extended the usability of these instruments in open channels; however, there were limitations caused by instruments operating at a single frequency that reduced the dynamic measurement range of the instrument. A recent advance in commercial microelectronics has greatly increased the capability of these devices intended for discharge measurements, including the ability to operate at multiple frequencies.

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Taking into account the increasing demand for water resources and the continuing concerns of the long term impact of global climate change has presented many end users the need for better accounting of water uses. Currently, in Australia there is a 10 year – hundreds of millions of dollars initiative for metering non-urban flow. Closer to home, the State of California has passed a number of Propositions, Proposition 50 for example, that would allocate tens of millions of dollars for the water resource monitoring and water use efficiency. In every case, these initiatives were developed with the idea to move from the old mechanical technologies to the newer highly accurate and precise technologies.

The importance of a good measurement is fundamental in the management and development of data; without good data the user can make poor and uninformed decisions. A good measurement is driven by site selection, the user's knowledge of "how to" make a proper measurement and measurement instrument capabilities. Typically a good site is easily accessible and has a well defined cross-section or transect. Velocity profiles should be well distributed and flowing perpendicular to the cross-section to be measured. The user "know how" is a key factor for making a discharge measurement and more often than not the user's knowledge of the instrument and the characteristics of the surrounding area guide the user to making an accurate measurement. Instrument capabilities are an important factor in accurately describing flow velocities which is translated into a discharge measurement by multiplying by discharge area. Describing all instrument characteristics is beyond the scope of this paper; however this paper will describe the latest developments in hydro acoustics and presents 5 case studies applying the RiverSurveyor.

Multi – frequency ADP

There are several key developments for the RiverSurveyor that will provide discharge measurement end users with increased accuracy and precision as well as ease of use. The application of multi-frequencies to the acoustic Doppler profiler (ADP) gives the user increased accuracy and precision on shallow to deep measurements without changing modes or configurations. Figure 1 and Figure 2 display schematics for the 5-beam S5 and the 9-beam M9, respectively.

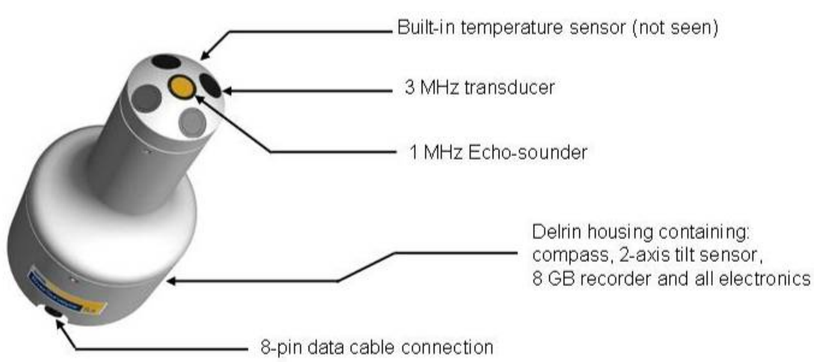

Figure 1. S5 RiverSurveyor ADP

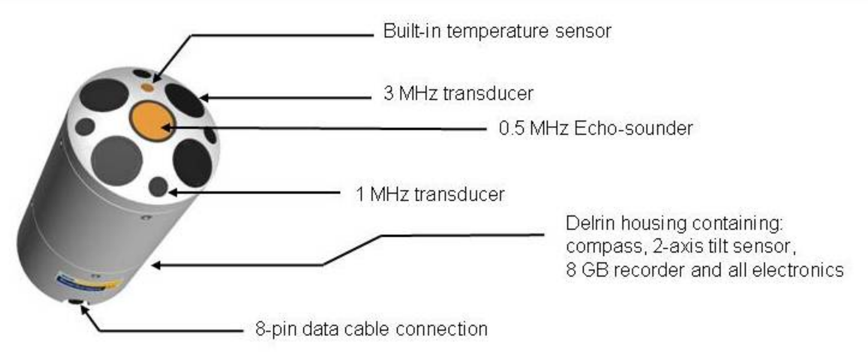

Figure 2. M9 RiverSurveyor ADP

The S5 uses a 1 MHz echo sounder for depth measurement with 4 – 3.0 MHz transducers for bottoming tracking and velocity profiling. The M9 utilizes a 0.5 MHz vertical beam with 4 – 3.0 MHz and 4 – 1.0 MHz transducers for bottom tracking and velocity profiling. In all cases the velocity profiling transducers are configured using a Janus 25° slant angle. The new multi frequency design compounded with increased profiling and depth measurements present the users significant improvements for discharge measurements. Table 1 displays depth and velocity profiling ranges

Table 1. Summary of transducer frequencies and profiling ranges for the S5 and M9

ADP Type	Velocity Profiling Frequencies (MHz)	Vertical Beam Frequency (MHz)	Velocity Profiling Range (ft)	Depth Measurement Range (ft)
S5	3.0	1.0	0.20 – 16	0.60 -49
M9	3.0/1.0	0.5	0.20 – 98	0.20 – 262

Power and Communications

The RiverSurveyor Power and Communications Module (PCM) provides integrated solutions for power, communications and navigational information. Each system is supplied with 2 rechargeable battery packs. Each battery pack provides the system power for 6+ hours. In addition, the unit has the capability for short or long range communications as well as GPS solutions. Figure 3 displays a drawing of the PCM and Figure 4 displays the SonTek Hydroboard which provides quick mounts for the ADP and PCM and is light weight enough for one man operation.

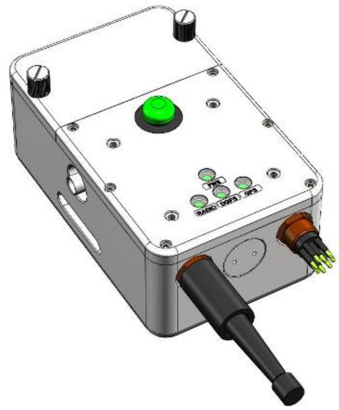

Figure 3. RiverSurveyor PCM

Figure 4. SonTek RiverSurveyor assembled on SonTek Hydroboard

The PCM uses Bluetooth technology for short-range communications while a 900 MHz spread spectrum radio is used for the long range communications. Short range communications utilizes a laptop which has a range up to 650 ft or a mobile phone platform that has a range up to 200 ft. The spread spectrum radio has a range to approximately 1 mile.
Table 2 presents a summary of communications options and corresponding range.

Table 2. Summary of communications options and corresponding ranges

Communications Type	**Range**
Bluetooth	Mobile 200 ft, Laptop PC 650 ft
900 MHz Spread Spectrum	1 mile

Additional Differential GPS (DGPS) with sub meter accuracy and Real-time Kinematic (RTK) GPS with 3 cm accuracy solutions are integrated into the PCM to provide highly accurate navigation data. These options provide end users a wide range of options for telemetry and present useful and accurate solutions for navigation that are ideal for moving bed situations. Table 3 presents a summary of GPS type and accuracy.

Table 3. Summary of GPS options and corresponding accuracy

Integrated GPS Option	**Accuracy (ft)**
Differential GPS (DGPS)	< 3.3
Real-time kinematic GPS (RTK)	≤ 0.01

<u>Ease of Use</u>

The Next Generation RiverSurveyor was developed with the user in mind; after a brief set-up there are on only five steps to complete a discharge measurement. Figure 5 presents the steps involved in the discharge measurement process. The software design allows the user to measure discharge from shallow to deep water without changing modes or cell sizes, settings automatically change by recognizing water depth and optimal resolution for the discharge measurement. In addition, the data are stored in the ADP making the measurement process stable and flexible. This is an important improvement as it allows the user to connect and disconnect from the ADP and still collect data. Previously all data were stored on the laptop with communications drops due range would require a complete re-start for data collection. Additionally, all Bottom Tracking, GPS and depth data are collected. This allows the user multiple options for discharge calculation during post processing.

Figure 5. Five steps in completing a discharge measurement

Note: Figure above is from the Mobile Platform; while the presentation on the laptop PC is slightly different the steps in the process are exactly the same.

CASE STUDIES

This section will provide a series of case studies explaining the use of the RiverSurveyor in a wide variety of conditions. The case studies include five canals near Yuma, Arizona area that were either a USGS or Imperial Irrigation District (IID)gauged/rated sites. All measurements applied USGS protocols and were conducted on January 15 and 16. Figure 6 presents gauging sites used in this paper.

Figure 6. Locations of gauging sites for case studies

Figure 7 presents a graphical summary of the M9 data collected on the All American Canal –Station 60. The graph in the top portion of the figure compares Bottom Track (BT) and Vertical Beam (VB) data. The Depth Reference data shows good agreement; however the VB better represents the trapezoidal canal, while BT has the tendency to round off corners due to depth determination being the average of the 4 beams in a 25° Janus configuration. The middle graph presents Track Reference data which also provides good agreement. The bottom graph presents velocity profile information across the measured transaction; note the cell velocities go from blue (slow) to red (fast). Overall performance of this site was optimal. It is important to observe that the RiverSurveyor measurement for the site was 3.5% less the gauged value. Observations made at the site indicate that instruments used in development of the rating curve had a much higher standard deviation (on the order of 10-fold or more) than the RiverSurveyor measurements conducted at the site.

Table 4 presents a summary of the data collected in the field. The table provides details for Track and Depth References used for the measurements. It can be observed from the data that overall system performance was excellent with covariance measurements ranging between 0.004 - 0.044 (or 0.4 - 4.4%) while the difference from gauged values ranged from -3.5 - +0.4%. It is important to consider that rating curves for the site were developed using different instruments.

Figure 7 presents a graphical summary of the M9 data collected on the All American Canal –Station 60. The graph in the top portion of the figure compares Bottom Track (BT) and Vertical Beam (VB) data. The Depth Reference data shows good agreement;

however the VB better represents the trapezoidal canal, while BT has the tendency to round off corners due to depth determination being the average of the 4 beams in a 25° Janus configuration. The middle graph presents Track Reference data which also provides good agreement. The bottom graph presents velocity profile information across the measured transaction; note the cell velocities go from blue (slow) to red (fast). Overall performance of this site was optimal. It is important to observe that the RiverSurveyor measurement for the site was 3.5% less the gauged value. Observations made at the site indicate that instruments used in development of the rating curve had a much higher standard deviation (on the order of 10-fold or more) than the RiverSurveyor measurements conducted at the site.

Table 4. Summary of data collected in the Lower Colorado River Basin

Station	**Q_{RS} (ft^3/s)**	**Track/Depth**	**STD DEV**	**COV**	**Q_{Gauge} (ft^3/s)**	**% Dif**
All American Station 60	4575	RTK*/VB+	18.85	0.004	4740	-3.5
Gila Gravity Main	857	Bottom Track/Beam	12.92	0.015	854	+0.4
Reservation Main	98	VTG#/VB+	4.29	0.044	100	-2.0
Welton Mohawk Main	469	RTK*/VB+	6.08	0.013	470	---
Welton Mohawk Drain	188	RTK*/VB+	3.14	0.017	187	---

*RTK refers to Real Time Kinematic GPS

+VB refers to Vertical Beam

#VTG refers to the VTG GPS string using a differential GPS correction

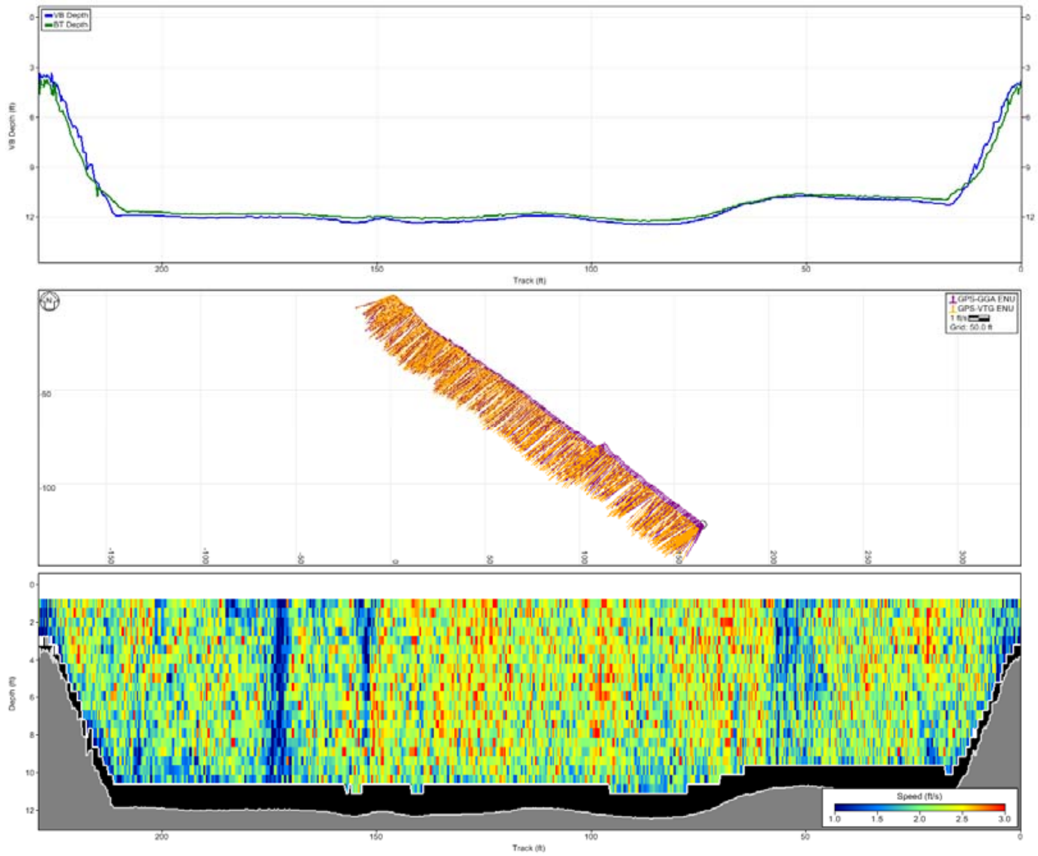

Figure 7. Data View - All American Canal Station 60

Figure 8 displays M9 data collected Gila Gravity Main Canal. The Gila Gravity Main Canal is a considerably smaller trapezoidal concrete channel than the All American Canal Station 60, however performance was similar recording a covariance of 0.015 (precision) for the four transects with a 0.4% difference from gauge rating. Depth Reference data was good with only slight variations observed in BT and VB data, while the same conclusions can be applied to Track Reference information. The bottom graph in Figure 8 displays velocity profile data (cell velocity data). It can be observed in this data that cell sizes on the left and right margins are larger that the cells in the middle of the transect. This can be explained by the M9 shifting from the 3 MHz transducers to the 1 MHz transducers, cell size and frequency hopping are done automatically based on depth.

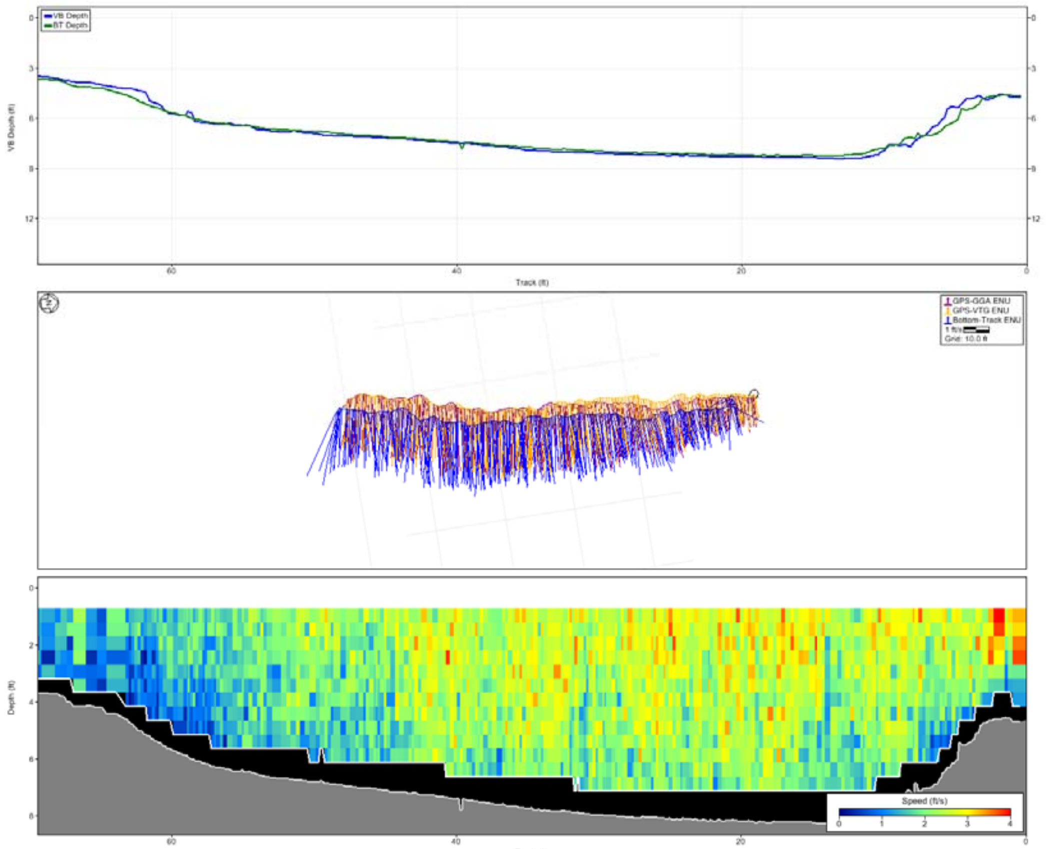

Figure 8. Data View – Gila Gravity Canal

Figure 9 highlights the S5 data from the Reservation Main Canal (USGS Station 09522500). The S5 collected almost equivalent data for Depth and Track Reference data for the earthen channel. BT data was not used in this case as the Reservation Main Canal is an earthen canal with deposits fine sediments on the bottom of the canal which proposes a potential problem for a moving bed. RTK GPS was not utilized for this paper in an effort to evaluate the performance of the VTG Track data in small to medium sized canals. Overall performance was good with a 0.044 value for Covariance and a -2.0% difference with the rated value. Observations can be made from the bottom graph as velocity profiling cell sizes changed automatically from smaller sizes (5 cm) on the edges to larger cell sizes (15 cm) in the middle of the transect as depth of the canal increased.

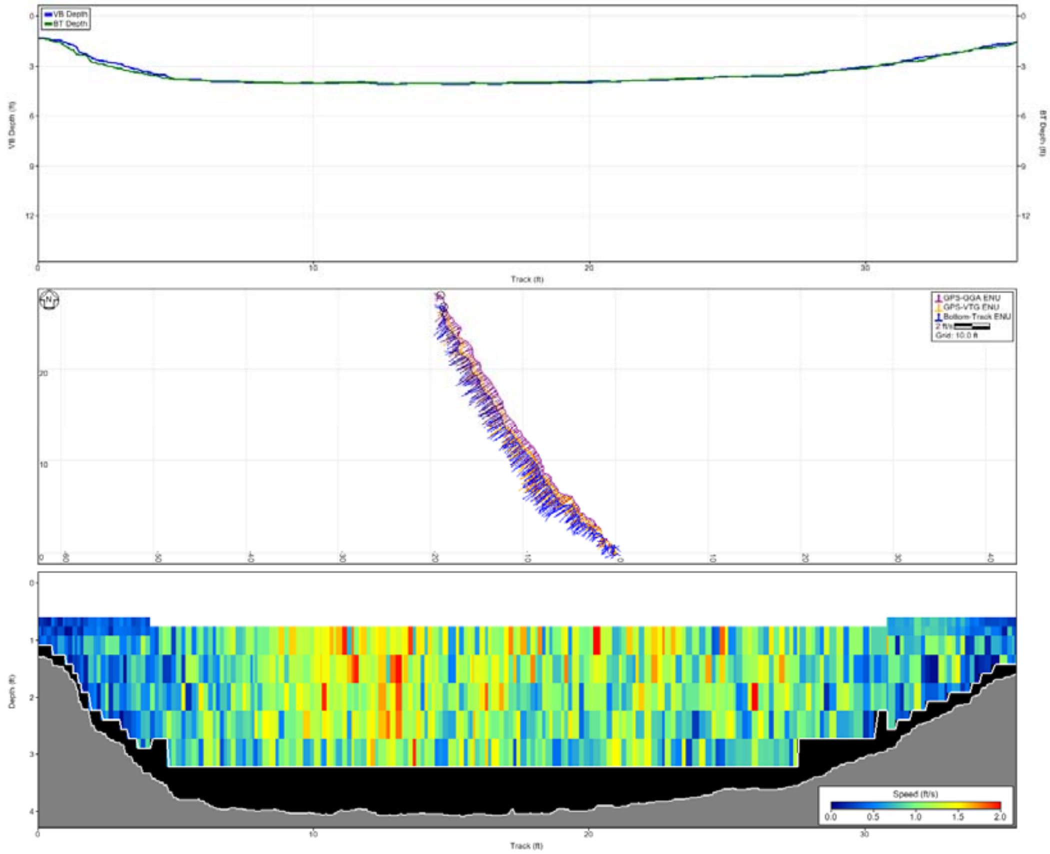

Figure 9. Data View – Reservation Main

Figure 10 presents the data collected at the Welton Mohawk Main Canal using RTK GPS for Track Reference and the VB for Depth Reference. Results of gaugings for the trapezoidal concrete canal were identical to the rated value (470 cfs) with a standard deviation of 6.08 cfs and a covariance of 0.013. Observations of the data indicate that the left edge has a significant build-up of sediments, approximately 3-ft with the highest velocities measured on the right edge of the canal. The Depth Reference data had slight discrepancies and this can be attributed to the steep walled trapezoidal canal and the depth calculation of the beam data and corresponding calculation. All Track Reference data were consistent with each other indicating that all data were valid for this gauging. It can be observed from the bottom graph that at approximately 8-ft of depth, the S5 automatically shifted from 5 cm cell size to a 15 cm cell size.

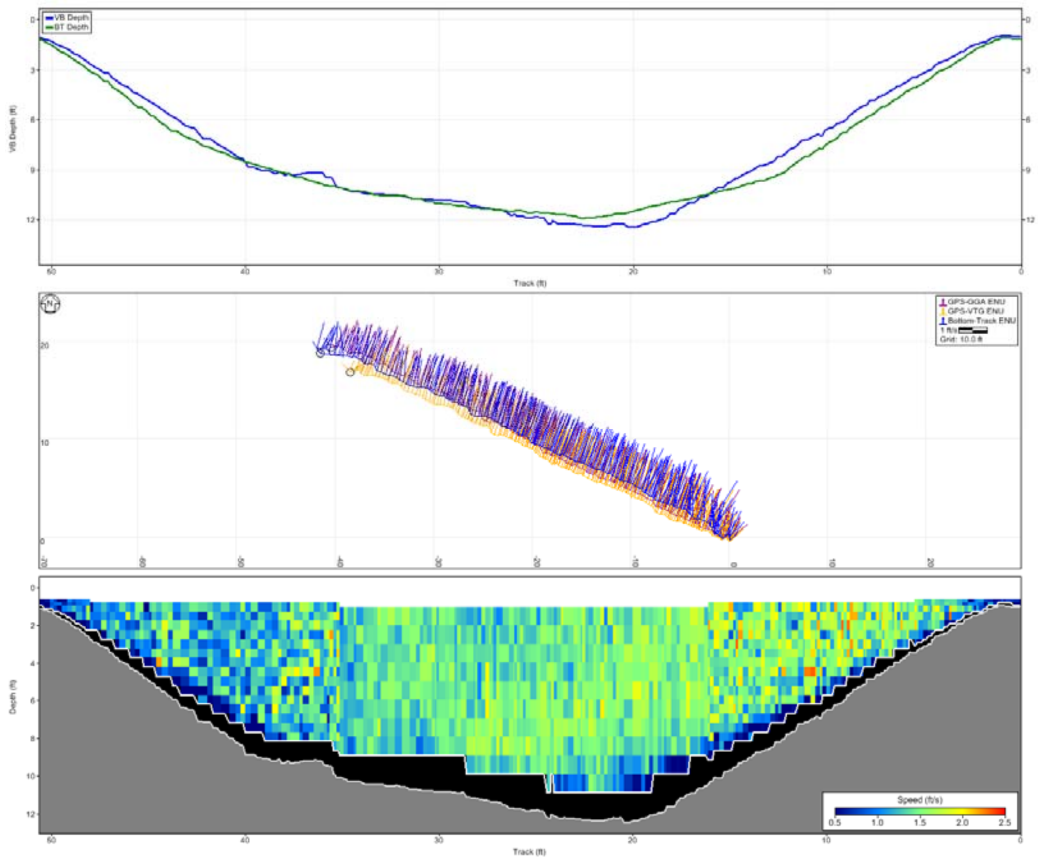

Figure 10. Data View - Welton Mohawk Main

Figure 11 presents data collected at the Welton Mohawk Drain. Depth Reference data was good with only slight differences observed in the BT and VB data. However Tack Reference data shows a major discrepancy between the GPS data and the BT data. The BT data indicates the track moving upstream while the GPS data presents a fairly straight line closing the transect. BT data indicates the presence of a moving bed therefore this data is not valid for the discharge measurement. Using the RTK GPS track information and VB data for Depth Reference the S5 data matched the rated values, with the S5 data presenting a standard deviation of 3.14 cfs (covariance of 0.017). Observations at the site indicated the presence of thick algae attached the bottom of the concrete lined channel. These algae would bias the Track data, making it appear that the rover is moving upstream; this also would bias the velocity data by decreasing the water velocity measurements and therefore decreasing the overall measured discharge.

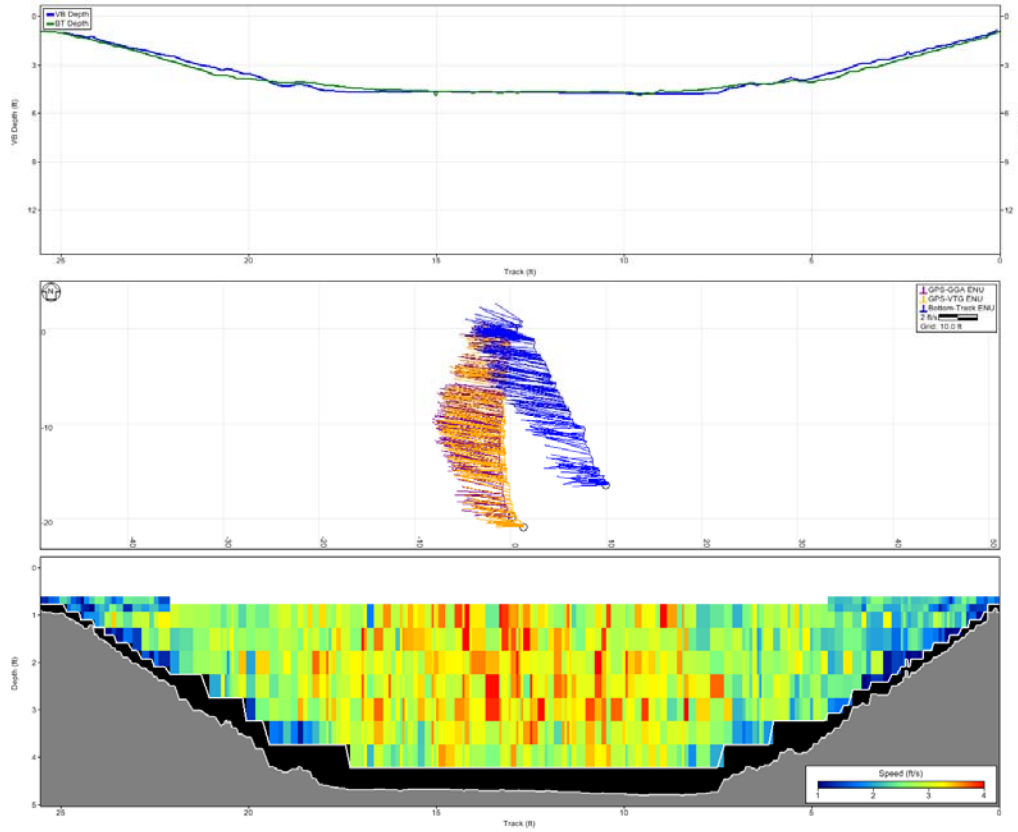

Figure 11. Data View – Welton Mohawk Drain

CONCLUSIONS

The case studies presented above indicate the RiverSurveyor is highly accurate when comparing discharge measurements to rated values of the USGS and IID, overall percent differences range from -3.5 to +0.4 % . In addition, that data presented demonstrates a high level of precision of the measurements with covariance ranging from 0.004 to 0.044. The multiple Track and Depth data provide valuable information about the measured sites, such as sediment build up, velocity profile data and detection of moving beds.

The system provides a high degree of flexibility, collecting multiple Track and Depth data references which allow the user many options in post processing and discharge measurement calculations. The examples above described combining the vertical beam with RTK GPS, Beam and VTG GPS data to determine discharge. Best case scenario would be to always have RTK GPS information available in order to make viable measurements in the case of moving bed sites which are typical of flooding events, plant growth and other potential complications.

The system is easy to use with site set-up and preparation taking less than 10 minutes, which includes obtaining an RTK lock. Data collection follows the 5 steps described above while the RiverSurveyor applies automatic cell size adjustments based on water depth, this allows users to focus on the process of data collection and not instrument configuration.

CAPAY DIVERSION DAM MODERNIZATION FOR SUSTAINED IRRIGATION DEMAND

George V. Sabol, PhD, PE[1]
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Michael Horgan[3]

ABSTRACT

The Yolo County Flood Control & Water Conservation District (District) releases about 250,000 acre-feet per year from two water supply reservoirs in the Cache Creek watershed for the irrigation of about 60,000 acres of farmland in Yolo County, California. That water is diverted into the Winters Canal and the West Adams Canal at Capay Diversion Dam on Cache Creek. The continued operation of Capay Dam is vital to the sustained future of irrigated agriculture of the District.

Urbanization and infrastructure construction in California resulted in extensive sand and gravel extraction from Cache Creek downstream of Capay Dam. Although that mineral extraction ceased many years ago, the streambed of Cache Creek has degraded. Presently the streambed elevation at the toe of Capay Dam is as much as 15 feet below the elevation of the apron of the dam and the dam is at risk due to downstream channel bed degradation and local scour during floods.

Capay Dam is a concrete diversion that was constructed in 1915. The main portion of the dam is an overflow section about 475 feet long with low-level sluice gates and service spillways at both abutments. The abutments also contain the headworks for the irrigation canals. Due to streambed degradation, local scour at the toe of the apron and the more than 90-year service life of the structure, the District embarked on a program of dam inspection, including the use of non destructive testing of the concrete, and rehabilitating the dam and headworks so as to continue to provide a sustainable irrigation supply of surface water from Cache Creek. The dam inspection and rehabilitation and betterment program for Capay Diversion Dam is presented. This includes the issues of environmental permitting, stream morphology, sediment transport and historic data collection.

INTRODUCTION

Agriculture plays a key role in Yolo County, California's heritage and economy. Almost 99 percent (more than 600,000 acres) of its unincorporated land is designated for agricultural use. The Yolo County Flood Control & Water Conservation District (District) provides irrigation water to about 60,000 acres. Depending on water supply in its two upstream water supply reservoirs (Clear Lake and Indian Valley Reservoir), the

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District releases about 250,000 acre-feet of water during the irrigation season. That water is diverted from Cache Creek into two main canals, the Winters Canal and West Adams Canal, at the Capay Diversion Dam. From Capay Dam, water from Cache Creek is delivered via nearly 175 miles of canals and laterals. The continued and reliable operation of Capay Dam is vital to the sustained future of irrigated agriculture in Yolo County. An aerial photo of the District showing the location of Capay Diversion Dam is provided in Figure 1.

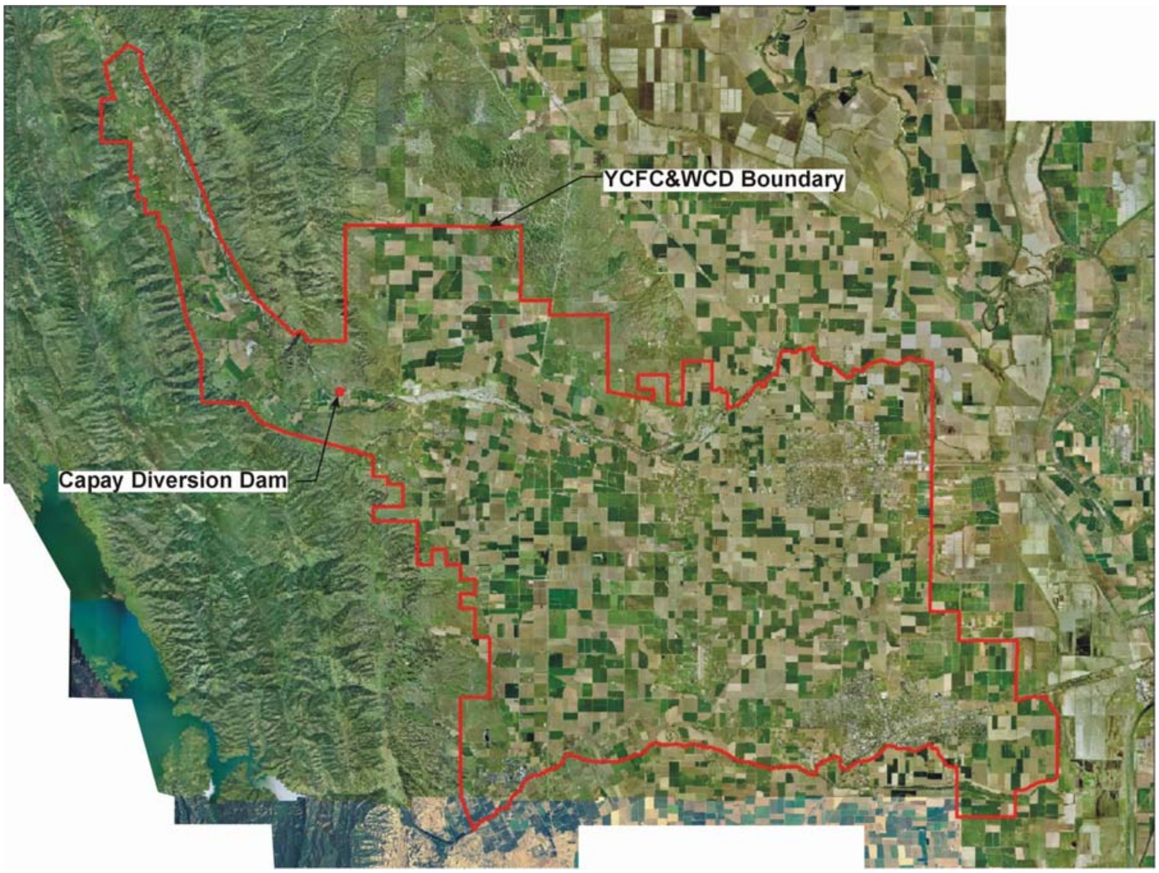

Figure 1. Yolo County Flood Control & Water Conservation District Boundary and Location of Capay Diversion Dam

Cache Creek is a valuable economic resource to Yolo County. Irrigation diversions began prior to 1850. Near the turn of the century, extensive canals and laterals were constructed to serve the agricultural demand. Besides water, Cache Creek is a major regional source of sand and gravel for the construction industry. Extensive rock product extraction from the creek accelerated in the 1950s. Cache Creek experienced streambed degradation from the mineral extraction which was exacerbated by other anthropogenic influences to Cache Creek. The geomorphic changes to Cache Creek resulted in streambed degradation at Capay Dam of more than 15 feet since the dam was constructed. In the 1990s, concern for Cache Creek resulted in a regional resource management plan.

Capay Diversion Dam

Capay Dam (Figures 2 and 3) is a concrete overflow diversion with headgates at each abutment. The Winters Canal headworks is in the right (looking downstream) abutment and the West Adams Canal headworks is in the left abutment. The dam was constructed in 1915. The overflow section is 475 feet long with low-level sluice gates and service spillways near each abutment. A short concrete apron extends downstream of the overflow section. The concrete overflow section is 10 feet high. The dam was originally fitted with timber flashboards that were repaired or replaced prior to each irrigation season. In 1993, a 5-foot high inflatable bladder was added to the crest of the dam so as to improve the efficiency of irrigation diversions while maintaining the dams' historic flood discharge capacity.

Figure 2. Aerial Photo of Capay Diversion Dam

Figure 3. Photo of Capay Diversion Dam showing Cache Creek streambed degradation and local scour at end of apron

In 2003, a section of the apron failed (Figure 4) resulting in an emergency repair. The cause of the partial apron failure was not confirmed but was probably due to the combined effect of streambed degradation, scour at the end of the apron, and concrete erosion of the apron due to sediment impact.

Capay Dam Inspection

In 2006, Capay Dam was subjected to a combination of review of design and operation records, and physical site inspection. This involved review of hydrologic records and analyses, hydraulic analyses including scour calculations, geologic and geotechnical investigations, concrete testing and structural analyses. In 2008, additional inspections, concrete testing and structural analysis were performed on the abutment walls. Major results of the inspections are:

1. The greatest threat to the dam is due to streambed degradation and local scour at the end of the apron. A new, longer apron and cutoff wall is needed.
2. The dam is unstable against overturning.
3. The emergency repair of the apron is in jeopardy of failing.
4. Sediment induced concrete erosion has occurred and may have contributed to the apron failure. Concrete erosion has damaged the piers that support the inflatable bladder deck.

5. The abutment walls are structurally distressed due to design and construction factors. Those walls do not have adequate factors of safety and need to be structurally reinforced.
6. There is seepage through cracks and construction joints in the dam. The upstream face of the dam needs to be inspected. That inspection is scheduled for 2009.
7. The headworks of both canals need repairs to the concrete and gates.

Apron Replacement

Alternatives for apron replacement were evaluated and the preferred alternative was selected. Apron replacement will be by use of roller compacted concrete (RCC). The apron will be lengthened to contain the energy of the hydraulic jump and a deeper cutoff wall will be employed to protect against local scour, (see Figure 5). The apron replacement will incorporate structural reinforcement of the abutment walls. A grade control structure will be constructed in Cache Creek a short distance downstream of the dam. That structure will provide protection of the dam against continued streambed degradation. Construction of the apron replacement is scheduled for fall 2009 at the end of the irrigation season. A major factor in the selection of RCC as the construction material is the short construction window between the end of the irrigation season and the start of the uncontrolled winter runoff in Cache Creek.

Figure 4. Partial failure of apron of Capay Diversion Dam in 2003

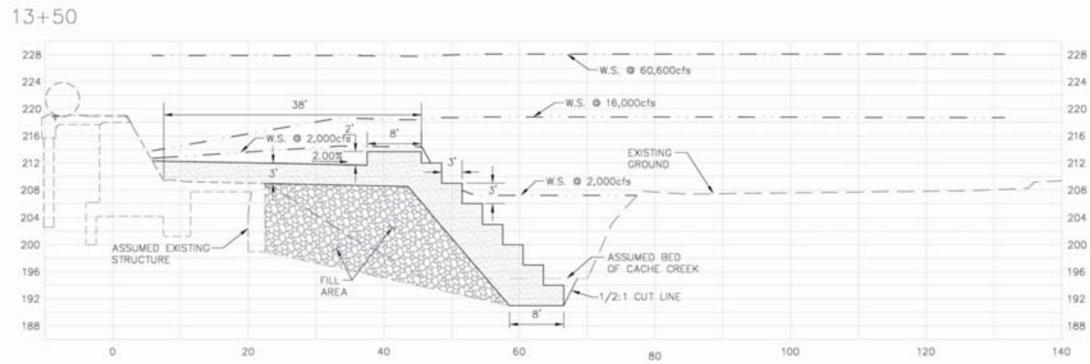

Figure 5. Illustration of replacement apron for Capay Diversion Dam

<u>Conclusions</u>

1. Watershed practices such as sand and gravel mining and other anthropogenic influences can adversely impact structures such as diversion dams in watercourses.
2. Conditions, such as streambed degradation, can develop over time that jeopardize diversion dams and headworks.
3. Hydraulic design practices of old irrigation structures may not provide adequate factors of safety against failure.
4. Construction, material specifications and quality control practices of old structures can lead to structural degradation.
5. Irrigation structures, such as diversion dams, need preventative maintenance and periodic inspection.
6. Modern material testing methods are cost effective in assessing the integrity of irrigation structures.
7. Sediment induced erosion of concrete can result or contribute to failures.

IMPROVING MILLERTON LAKE FLOOD CONTROL OPERATIONS TO INCREASE WATER SUPPLY

A.Buelna, P.E.[1]
D. DeFlitch[2]
K. Lee[3]

ABSTRACT

The objective of this paper is to familiarize the audience with the operations of the Friant Division of the Central Valley Project (CVP), the operations of Friant Dam, Millerton Lake for the 2006 water year, and the Upper San Joaquin River Basin Model (USAN). Finally, the paper will discuss the potential effects of Friant water supply in the context of climate change.

INTRODUCTION

The settlement and development of the western United States (U.S.) was more dependent upon the availability of water than any other factor. As such, the U.S. Federal Government aimed to populate and enhance the West through the creation of water projects. In 1902, President Theodore Roosevelt signed into law the Reclamation Act (32 Stat. 388) which created the U.S. Reclamation Service (later to become the Bureau of Reclamation). The main intent of the Reclamation Act of 1902 was to settle the West by developing and providing water to individuals for the establishment of small-scale family farms (less than 160 acres or 65 hectares).[4] The CVP of California represents a significant part of Reclamation's facilities in the West.

Watershed and Supplies

The Central Valley (Valley) basin (Figure 1) includes two major watersheds: the Sacramento River in the north and the San Joaquin River in the south. The combined watersheds extend nearly 500 miles (805 km) in a northwest-southeast direction and average about 120 miles (193 km) in width.

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[4] Layperson's Guide to the Central Valley Project, prepared by the Water Education Foundation, Sacramento, CA, 1994, pp. 4,5

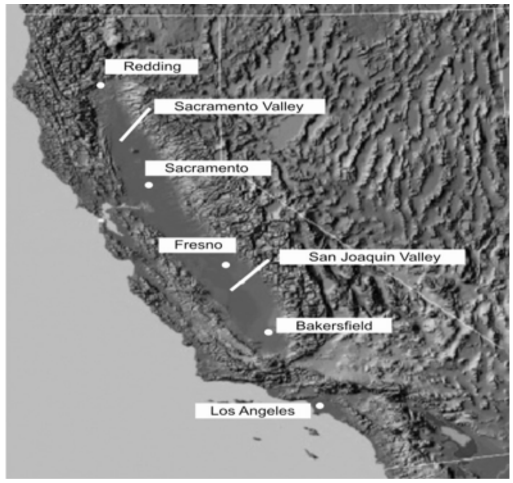

Figure 1. California Central Valley

The Valley is a large bowl-shaped feature surrounded by mountains except for a gap in its western edge (at the Carquinez Strait). The Valley floor occupies about one-third of the basin; the other two-thirds are mountainous. The Cascade Range on the north and the Sierra Nevada on the east rise in elevation to 14,000 feet (4,267 m) or higher. The Coast Range on the west is as high as 8,000 feet (2,438 m).

The Sacramento River and its tributaries flow southward draining the northern part of the Valley basin. The San Joaquin River and its tributaries flow northward, draining the central and southern portions. The two river systems join at the Sacramento-San Joaquin Delta, flow through the Carquinez Strait into San Francisco Bay, and thence into the Pacific Ocean. The average annual natural runoff of the Central Valley basin from the period 1903 through 1963 was about 33 million acre-feet (40.7 billion cubic meters). For the critical seven-year dry period from 1927 to 1933, average annual runoff was 18 million acre-feet (22.2 billion cubic meters). The average annual historical runoff in acre-feet (a.f.)(million cubic meters) at four major dams of the CVP is as follows:

Table 1. Average Annual Historical Runoff[5]

Dam	**Stream**	**1956-2005 [50-year average]**	**1927-1934 [7-year average]**
Shasta	Sacramento	6,107,000 (7,533)	3,650,000 (4,502)
Friant	San Joaquin	1,836,000 (2,265)	1,040,000 (1,283)
Folsom	American	2,719,000 (3,354)	1,560,000 (1,924)
Trinity	Trinity	1,398,000 (1,724)	680,000 (839)

[5] CVP Watershed Data, Mid-Pacific Region, Office of Public Affairs, Sacramento, CA, 2008

Introduction to Central Valley Project – Friant Division

The Friant Division (Figure 2) is a portion of the CVP. It delivers water to more than 1 million acres (~405,000 hectares) of irrigable farm land on the east side of the southern San Joaquin Valley from approximately Chowchilla in the north to the Tehachapi Mountains in the south. The main features of this division are Friant Dam, Friant-Kern Canal, and Madera Canal. These facilities were constructed and originally operated by Reclamation.

Figure 2. Major Central Valley Project Facilities

Friant Dam and Millerton Lake[6]

Friant Dam is located on the San Joaquin River 25 miles (40 km) northeast of Fresno, California, below a drainage area of 1,630 square miles (~4,222 square km). Largely completed in 1942, the dam is a concrete gravity structure standing 319 feet (97 m) high with a crest length of 3,488 feet (1,063 m).

It controls the flow of the San Joaquin River. Friant Dam and Millerton Lake are used for both flood control and water conservation to meet irrigation and municipal and industrial demands. They provide downstream releases to meet pre-CVP water right requirements above Mendota Pool and provide flood control, conservation storage, and diversion into the Friant-Kern Canal and Madera Canal. The reservoir, Millerton Lake, has a capacity of 520,500 a.f. (642 million cubic meters).

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[6] Friant Dam and Millerton Lake Factsheet, Mid-Pacific Region, Office of Public Affairs, Sacramento, CA, 2008

Friant-Kern Canal and Madera Canal

The Friant-Kern Canal conveys water from Millerton Lake that is distributed to contracting irrigation districts, water districts, and cities in Fresno, Tulare, and Kern Counties. Construction of the canal began in 1945 and was completed in 1951. The canal is 151.2 miles (244 km) long and has an initial capacity of 5,300 cubic feet per second (cfs) (150.1 cubic meters per second [cms]). The capacity gradually decreases to 2,500 cfs (70.8 cms) at its terminus in the Kern River, on the west side of the city of Bakersfield.

The 35.9 mile-long (57.7 km) Madera Canal conveys water that is distributed to water districts in Madera County. The canal, completed in 1945, has an initial capacity of 1,250 cfs (35.4 cms), decreasing to a capacity of 625 cfs (17.7 cms) at the Chowchilla River.

Upstream Storage and Routing

Upstream of Millerton Lake, there are nine major and several minor reservoirs that store and release water for purposes of power production, recreation, and maintenance of stream flows. Both Southern California Edison (SCE) and Pacific Gas and Electric (PG&E) are privately owned public utilities that own and operate these facilities. Several of the reservoirs are connected through conduits or tunnels that can convey water between adjoining watersheds (Figure 3).

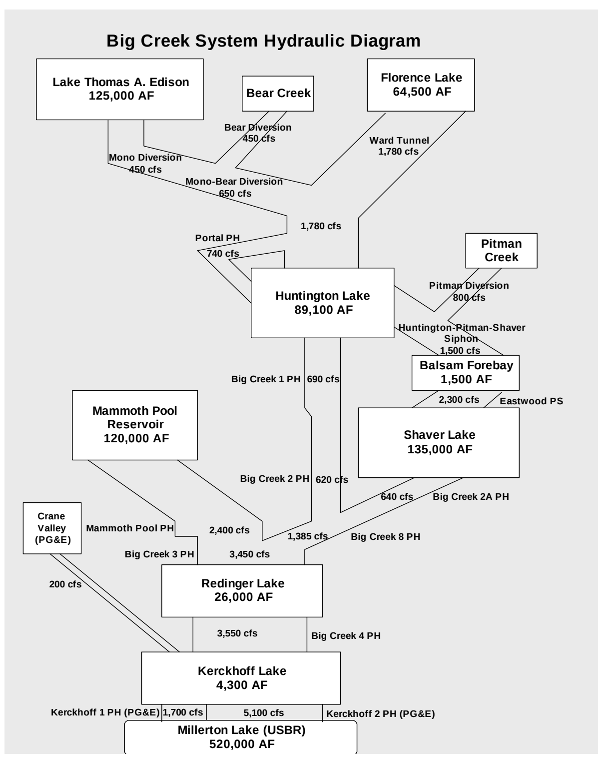

Figure 3. Upstream Reservoirs

SCE and PG&E typically capture spring runoff for power generation and influence the timing and rate of inflow to Millerton Lake. The water from the San Joaquin River basin is said to be the hardest working water in the world.[7] It runs through as many as eleven powerhouses before finally infiltrating the ground. Once it reaches Millerton Lake, it is either released from Friant Dam down the San Joaquin River or diverted to either the Friant-Kern Canal or Madera Canal where it will be used for irrigation and municipal and industrial purposes. On February 1 each year, both PG&E and SCE submit their water operation plans to Reclamation for review.

MILLERTON LAKE OPERATIONS

Normal Operations

Eight dams located upstream of Friant Dam are operated and maintained by SCE. The Mammoth Pool Agreement, a 1957 contract between SCE and Reclamation, prescribes how SCE will operate their facilities. PG&E operates one dam (and other ancillary facilities) upstream of Friant Dam. The Miller-Lux Agreement, which is a 1909 contract between Reclamation and PG&E, prescribes how PG&E will operate these facilities. The upstream projects have a significant amount of reservoir storage which could dramatically affect the amount of naturally occurring runoff that would occur as inflow into Millerton Lake from one year to the next. Both of these agreements provide assurances to Reclamation of the amount of runoff in a year that will be released to Millerton Lake and become inflow.

Before February 20 each year, Reclamation's South-Central California Area Office (SCCAO) Operations Division notifies each irrigation and municipal and industrial water user with a long-term contract of the estimated water available for that year (March 1 through the following February). This allocation is based on the State of California, Department of Water Resources (DWR) February 1 forecast. Beginning February 1, DWR prepares an unimpaired flow forecast based on snow amounts. DWR publishes the forecast on its Web site.[8] Water users then send in schedules showing the quantities of water each plan will use each month during the contract year. The SCCAO Operations Division then summarizes the users' schedules. Based on the DWR forecast, SCE Water Management Plan, PG&E Water Management Plan, and water delivery schedules, Reclamation develops its initial Water Supply Forecast taking into account the 90 percent exceedance, 50 percent exceedance, and 10 percent exceedance forecasts.

Each subsequent month (until June or July), a revised Water Supply Forecast is prepared with the most recent DWR forecast, hydrological data, and user demands. This information is again summarized by the SCCAO Operations Division and presented to the water users[9] during a monthly Engineers-Managers meeting. Ten days following the meeting, a standing request for revised water schedules is prepared by the water users and

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[7] Internet Resource - http://www.sce.com/Feature/Archive/hydropowerfeature.htm accessed May-Sept. 2008

[8] Internet Resource - http://cdec.water.ca.gov/ accessed May-Sept. 2008.

[9] Friant Districts, Friant Water Authority and Friant Water Users Authority, Lindsay, CA, 2008

sent to the SCCAO. The SCCAO Operations Division summarizes the “new” schedules and develops the Millerton Lake Operation Forecast of Water Supply and Requirements.

Flood Operations and Flood Characteristics

Floods in the upper San Joaquin River basin occur about four out of ten years. There are two general types of floods: rain and snowmelt. Rain floods primarily are the result of intense rainfall in the mountains. Snowmelt floods primarily are the result of mountain snowmelt.

Rain floods occur mostly in the months of November through March and are characterized by high peak discharges caused by heavy general rains, sometimes augmented by melting snows at intermediate elevations. High river stages last only a few days, and runoff volumes are comparably small. Rain flood size in the San Joaquin River basin typically varies depending upon storm precipitation and latitude. If it is a ‘cold’ storm with prevailing winds coming from the north, then it is likely to be a smaller event. Conversely, if it is a ‘warm’ storm with prevailing winds from the south, there is a greater chance for precipitation at higher elevations and a larger event. Among the largest rain floods on the San Joaquin River during the period of record (1896 to present) are those that occurred in January 1911, December 1937, December 1955, January 1969, and January 1997. The largest rain flood occurred on January 2, 1997, and had an estimated maximum unregulated daily flow of 77,500 cfs (2,195cms) and a seven-day volume of 416,700 a.f. (514 million cubic meters). Reportedly, the legendary floods of December 1862 and 1867 were larger than the January 1997 flood; unfortunately, no reliable flood data are available for these events.

Generally throughout the watershed, most of the precipitation falls as snow above 5,000 feet (1524 m) in elevation and remains in the mountains until spring. Snowmelt floods are characterized by sustained, moderate flows for 2-3 months, yielding large volumes of runoff. Snowmelt runoff may cause damage in the San Joaquin Valley by prolonging high stages in the lower channels, inundating low-lying swales during part of the growing season, and causing seepage through levees above Mendota Dam. The largest snowmelt flood of record on the San Joaquin River above Friant Dam was in 1906, with a maximum mean daily flow of 26,300 cfs (745 cms) and an April-July volume of 3.34 million acre-feet (4.12 billion cubic meters). The second largest snowmelt flood occurred in 1969, which had an unregulated maximum mean daily flow of 24,500 cfs (694 cms) and an April-July volume of 2.9 million acre-feet (3.58 billion cubic meters).

Areas along the San Joaquin River downstream of Friant Dam that are subject to flooding at releases greater than 8,000 cfs (226.5 cms) consist of a mobile home park upstream of State Highway 41 in Madera County just north of Fresno and the east side of the town of Firebaugh downstream of Mendota Dam. Most of the flood water stays within the confines of dedicated floodways and enters natural overflow basins.

Flood Operating Criteria

Friant Dam is operated for flood control purposes in accordance with guidance provided by the U.S. Army Corps of Engineers. Guidance documentation is provided for in the Flood Control Storage Reservation Diagram.[10]

Flood control operations of Friant Dam and Millerton Lake establish:

- Restricting the release of flows to the San Joaquin River from the reservoir to a variable quantity of up to 8,000 cfs (226.5 cms), depending on the following:
    - Magnitude of flow entering the river from tributaries of Little Dry and Cottonwood Creeks, which enter the San Joaquin River downstream of Friant Dam, or
    - Flow entering the river above Mendota Pool from the Kings River North.
- Reserve storage space in the reservoir on the basis of the Flood Control Storage Reservation Diagram (Figure 4), which indicates variable storage space requirements according to the current flood hazard.

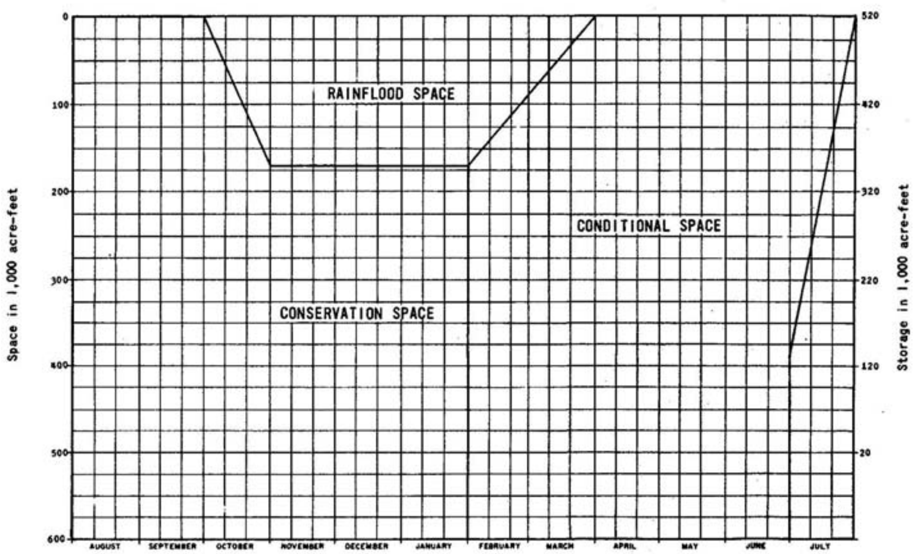

Figure 4. Flood Control Storage Reservation Diagram

Flood control operation each day during the rain flood season (October 1 through April 1) consists of determining the required storage space reservation 24 hours in advance and scheduling releases to provide the required space reservation by the end of the day, whenever possible. This space represents a compromise between flood control and conservation requirements.

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[10] U.S. Army Corps of Engineers, USACE, Department of the Army, Sacramento, CA., (1980), Chart A11

During the snowmelt runoff season, required space is determined as each runoff forecast becomes available and is adjusted daily for actual runoff and for changes in weather. The snowmelt space reservation varies according to the predicted full natural inflow from the area above Friant Dam between the given day and July 31. Adjustment of required space, as indicated by the snowmelt forecast parameter, is made when applicable in accordance with paragraphs four and five of the Flood Control Storage Reservation Diagram.[11]

Whenever encroachment into the required flood control reservation space occurs, releases (for irrigation or other requirements) are increased as rapidly as is feasible while minimizing storage in the flood control space, not exceeding the maximum value permitted by downstream flow criteria. As long as there is significant storage available in the flood control space, the rate of release is varied, as necessary, to maintain the permitted flows in the downstream channel. The required release for flood control during encroachment is determined from the Supplemental Release Control Diagram (Figure 5). This diagram indicates the total flood control release required in the flood season from October 1 to July 31. The requirements are as follows:

- Minimum storage space reservation for control of rain flood runoff, consisting of 170,000 a.f. (209.7 million cubic meters) from October 15 to March 1, increasing from zero on October 1 and decreasing again to zero on April 1.

- Supplemental rain flood space reservation up to a maximum of 85,000 a.f. (104.8 million cubic meters) from November 1 to February 1, increasing from zero on October 15 and decreasing again to zero on March 1.

- Supplemental space reservation for control of runoff from snowmelt up to a maximum of 390,000 a.f. (481.1 million cubic meters) from February 1 to July 1.

[11] U.S. Army Corps of Engineers, USACE, Department of the Army, Sacramento, CA., (1980), Chart A11

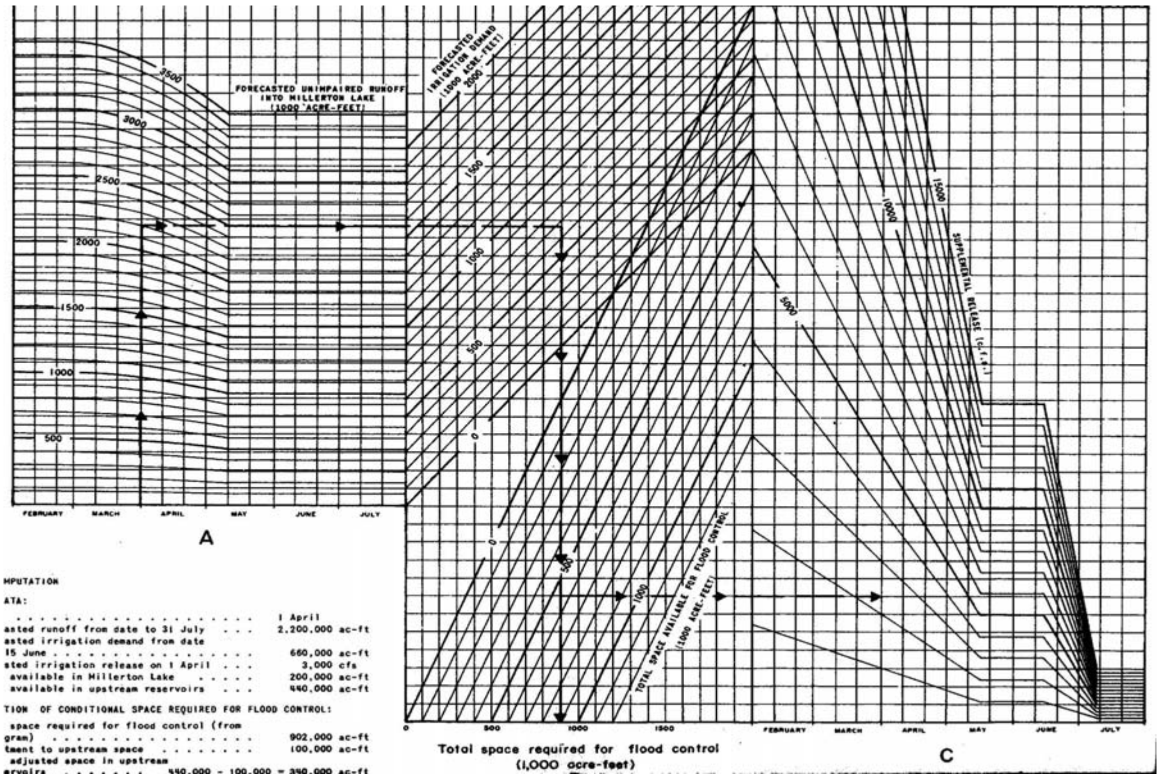

Figure 5. Supplemental Release Control Diagram

2006 OPERATIONS AT MILLERTON LAKE

Millerton Lake Operations

On March 1, 2006, the hydrologic conditions (Figure 6) of the San Joaquin River basin were approximately the historic average and the DWR 50 percent exceedance runoff forecast was 1.27 million a.f. (1.5 billion cubic meters) (Figure 7). The San Joaquin River release was also normal, and Millerton Lake was filling. By early April, Millerton Lake storage was at 95 percent of capacity. The 100-year average precipitation for April is about 3 inches (76.2 mm); however, the first week of April 2006 produced ten inches (254 mm) of rain or more than 300 percent of normal. This required channel capacity releases into the San Joaquin River.

Percent Error in Forecast

The forecasting error in early 2006 was approximately 11 percent (Figure 7). This equates to 270,000 a.f. (333 million cubic meters) or about 52 percent of the capacity of Millerton Lake. This forecasting error complicates operational timing when filling the lake and reducing flood control releases to the San Joaquin River. It supplies less flexibility when getting a spike in temperature and subsequently a greater snowmelt requiring a greater release. The impact is principally on downstream stakeholders.

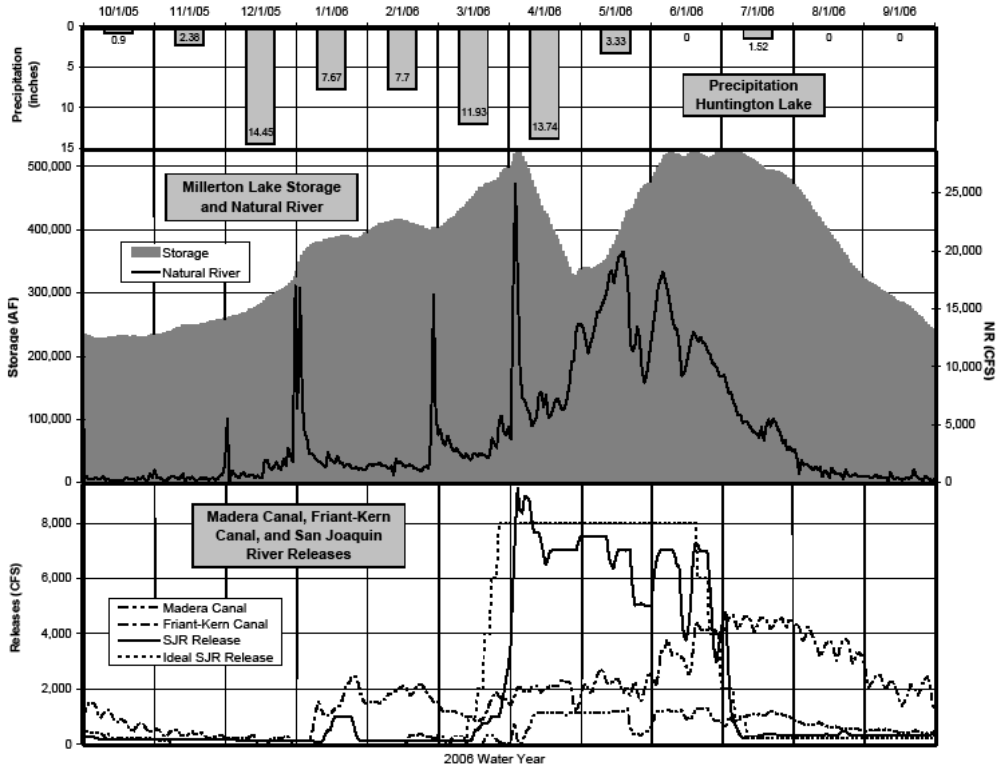

Figure 6. Supplemental Release Control Diagram

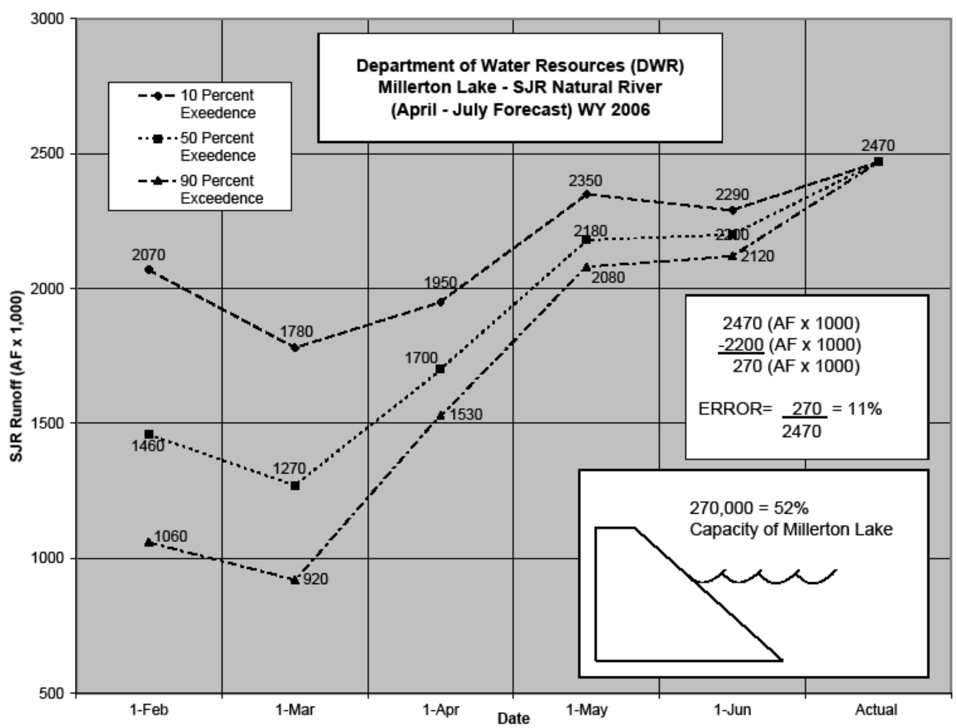

Figure 7. Supplemental Release Control Diagram

The penultimate operational objective for the reservoir is to fill Millerton Lake the same day as the flood control releases are reduced to a minimum. This requires the ability to predict the future, to foresee how various combinations of temperature and precipitation will affect the rate at which snow pack melts and change irrigation demands.

Forecast Versus Flood Release

In 2006, the forecast increased greatly each month, thereby prompting increases to be made in the flood release. In March 2006, the 50 percent exceedance forecast of 1.27 million a.f. (1.5 billion cubic meters) did not require flood releases (Figure 8). The drastic increase in the forecast for runoff just 1 month later sparked a necessary flood release of 511,000 a.f. (630 million cubic meters) (Figure 8). With each month that passes, the amount of time available to release a certain volume of flood water decreases. Any uncertainty in the forecast makes it extremely difficult to release flood volumes at a steady rate. Had the exact natural river for the 2006 water year been known, the ideal release of water into the San Joaquin River would have been much more steady (Figure 6).

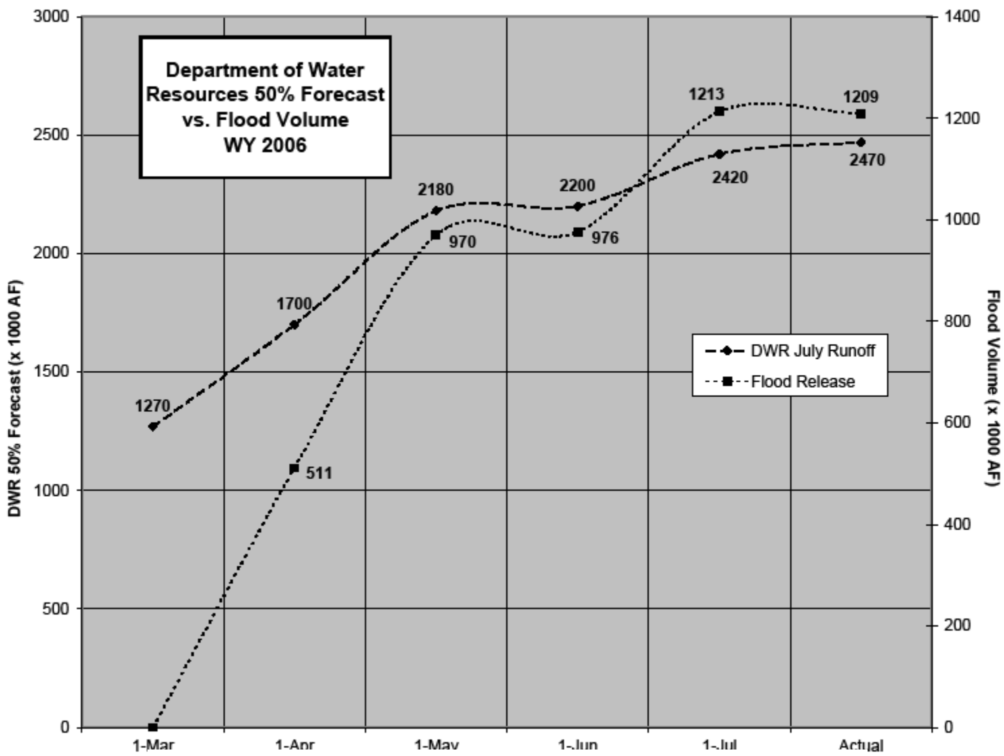

Figure 8. DWR Forecast vs. Flood Volume 2006

UPPER SAN JOAQUIN RIVER BASIN MODEL[12]

The Upper San Joaquin River Basin Model (USAN) was developed to study re-operation of the upstream reservoirs to enhance the Friant Division water supply. USAN uses historic hydrologic data (from 1896 to present) to simulate the operation of Millerton Lake and the major upstream reservoirs. Typical reservoir operation in USAN is guided

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[12] Madeheim, Huxley T., USAN, (2000)

by user-defined target storages on specific dates at all modeled reservoirs, stream release requirements, power releases, diversions to the Friant-Kern and Madera Canals, and unregulated snowmelt flow volume forecasts.

By utilizing the USAN computer model, Reclamation improves Millerton Lake operations and augments the Friant Division water supply. USAN can simulate real-time data from 1896 to the present. USAN is used daily by Reclamation to produce short-term reservoir operations with real-time data being used to update the USAN model (storage, delivers, releases, etc.). Forecasts (of upstream power operations, irrigation demand river releases, etc.) are included in the simulation of Millerton Lake operations.

Starting with each day's current conditions, any year from the historical database can be chosen and simulated by the model for subsequent conditions; thus, the system can produce more than 100 alternative scenarios. These runs can extend through the end of the water year.

USAN was also developed to aid the operation of the Friant Dam and Millerton Lake. It provides useful information in graphic and tabular form about flood control, water supply, daily releases, and storage.

Model

The model uses a daily time step of projected operations applied to historic unimpaired flow data. A systematic reservoir operation was developed based on the record of operations. The model was calibrated to historic river flows, canal diversions, and reservoir storage. The USAN was calibrated by adjusting the model operation variables until the simulation approximated the historic hydrologic records (river flow, canal diversions, and reservoir storage).

Model Limitations

USAN makes operational decisions based on forecasts. Upstream reservoir operation is based on the April-July unregulated flow forecast, and Millerton Lake operation is based on the February-July forecast plus February 1 storage. For upstream reservoir operation, the April-July forecast is updated each March. For Millerton Lake operation, the February-July forecast is updated each week from February 1 through April 1.

USAN uses the Millerton Lake February 1 storage plus the February-July unregulated flow forecast to determine the amount of water available for canal deliveries each year. Snowmelt flood releases may need to be increased in some years due to an increase in water supply as the season progressed. Project operators monitoring basin conditions on a daily basis or a more informed model (canal deliveries based on total basin storage or updated deliveries based on end of July conditions) could probably improve upon the results of the simulations.

USAN operation continually falls short with its flexibility to realistically model varying conditions or water years. The distribution of the snowmelt has shown to cause variations in excess of 100,000 a.f. (123 million cubic meters) in the volume of water available for diversion during snowmelts of equal volume. USAN should be updated to include a method of adjusting to upstream water supply and changes occurring during snowmelt season.

Precipitation Trends in the Upper Basin

Global warming is a major topic in the world today and is defined by the U..S. Environmental Protection Agency as "an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns." [13]

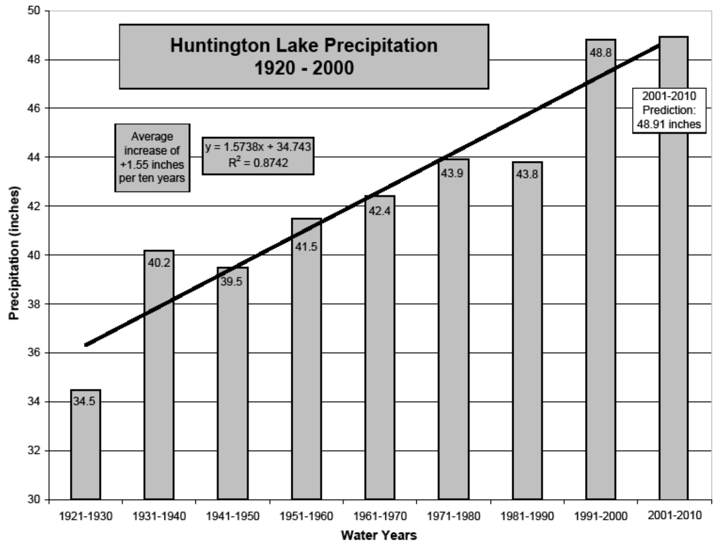

Figure 9. Huntington Lake Precipitation

According to National Oceanic and Atmospheric Administration and National Aeronautics and Space Administration data, "the Earth's average surface temperature has increased by about 1.2 to 1.4°F in the last 100 years."[14] Some of the effects of climate change which are important to Friant operations are changes in rainfall timing and intensity, total snow and ice coverage, and a rise in ambient temperature. Some recent models for the western U.S. indicate overall precipitation will increase.[15] [16] A limited look at the precipitation data recorded from Huntington Lake in the Upper San Joaquin River Basin tends to support this theory (Figure 9).

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[13] Internet Resource - http://www.epa.gov/climatechange/basicinfo.html accessed May-Sept. 2008

[14] Internet Resource - http://www.epa.gov/climatechange/basicinfo.html accessed May-Sept. 2008

[15] Kim, J., T.-K. Kim, R. W. Arritt, and N. L. Miller. "Impacts of Increased Atmospheric CO_2 on the Hydrolclimate of the Western United States." Journal of Climate 15: 1926-1943, (2002)

[16] Snyder, M. A., J. L. Bell, L. C. Sloan, P. B. Duffy, and B. Govindasamy. "Climate Responses to a Doubling of Atmospheric Carbon Dioxide for a Climatically Vulnerable Region." Geophysical Research Letters 29 (11): 10.1029/2001GL014431. (2002)

Higher temperatures are of particular concern for Central California water systems (like Friant) because of their effect on Sierra Nevada snow pack accumulation and snowmelt.[17] Increased temperatures alone could significantly reduce the Friant Division's total yield. Because Friant is a relatively small dam compared to its watershed, Reclamation has historically relied upon snow and ice to store and produce water throughout the spring and summer months. With the advent of climate change, there already exists strong documentation that total snow accumulation in the western U.S. has significantly declined over the period 1925-2000.[18] While higher temperatures threaten to reduce the overall accumulation in the Sierra Nevada by up to 80 percent, that reduction is closer to 40 percent in the highest Sierras which feed the San Joaquin River.[19]

Changes in rainfall, snowpack, and a rise in ambient temperature could have compound effects on the watershed and operations at Friant Dam, likely increasing the probability of a rain flood event and decreasing the magnitude of snowmelt flows. These potential changes in timing and intensity of runoff into Millerton Lake may eventually require that additional flexibility be built into reservoir operating criteria and apply to the benefits of additional storage to the San Joaquin River water supply under a changing climate.

SUMMARY

The San Joaquin River has two major runoff seasons, November through March, when most of the runoff is produced by rain, and April through July, when most of the runoff is produced by snowmelt. The snowmelt season produces approximately 70 percent of the annual water supply. From a detached perspective, it might seem fairly easy to operate Friant Dam and Millerton Lake while managing the Friant Division's CVP water supply, but when one considers all of the information needed to make operational decisions, the speculative nature of some of the information (especially early in the runoff period), the importance of the water supply to the end user, and the utmost importance of providing protection from floods, it becomes obvious that it is a complex task. It is a mission that requires close communication and coordination with many parties and a significant amount of professional judgment.

[17] Kiparsky, M. and Gleick, P. H. "Climate Change and California Water Resources: A Survey and Summary of the Literature." Public Interest Energy Research Final Project Report, Pacific Institute for Studies in Development, Environment, and Society, Oakland, CA., (2003), 545-610

[18] Mote P.W., Hamlet, A.F., Clark M. P., Lettenmaier D.P. 2005. "Declining Mountain snowpack in Western North America." American Meteorological Society DOI: 10.1175/BAMS-86-1-39, (2005)

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U.S. Army Corps of Engineers, USACE, Department of the Army, Sacramento, CA., (1980), Chart A11

DEVELOPMENT OF GIS BASIS TO SUPPORT INTEGRATED WATER MANAGEMENT AT DISTRICT LEVEL

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Dr. Moamen El-Sharkawy[2]

ABSTRACT

While progress with Integrated Water Resources Management (IWRM) is fundamental to sustainable development, a pre-requisite for furthering these processes is an effective computerized system that serves the data and information needs of all stakeholders, and promotes equity through good governance. Developing an IWRM information system is a challenge in developing countries with limited resources.

In most of the developing countries, water information systems at local administrative levels are generally absent or severely degraded, and management decisions are mostly based on unreliable data and information. A lack of data and obsolete data capture and/or information management systems are common issues, resulting in inadequate data/information to support IWRM implementation. An innovative, inclusive approach is required that will unleash the full benefit of a number of powerful technologies to capture, manage, and disseminate water related data and information, in a cost effective and sustainable manner.

The Egyptian Ministry of Water Resources and Irrigation has a long-term goal of reorganizing its internal functions and operations through a process of local governance consolidation and ministry-wide decentralization, including devolution of authority to the local government level. With that, the MWRI has adopted a policy to integrate all water management functions at the districts to support the decentralized management process.

Recognizing the utilization of a framework that comprises satellite data, survey tools, and package of software supported initiation of a base for integrated water resource management. This paper will discuss the support of the district water information system comprising digital mapping as one of the steps toward the development of the district information system and supporting the implementation of IWRM. The presented information system components can be introduced and implemented at the district or local level within the MWRI. It is anticipated that this district information system will be introduced and implemented by the MWRI at all districts in the near future.

INTRODUCTION

Under present operational and administrative conditions in the MWRI, the management of services is handled through line department directives and functions emanating from

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the central ministry to lower line offices at the inspectorate and district levels. The objectives of a policy reform were to move toward the goal of reorganization of the MWRI internal functions and operations including devolution of authority to the local level thereby decentralizing water management and eliminating district-level inefficiencies and redundancies.

An operational IWMD is expected to achieve the following targets:

- Improved water use efficiency
- Well-maintained irrigation and drainage system, and
- Improved service delivered to users.

The definition of what constitutes an Integrated Water Management District is as follows: *The Integrated Water Management District is an entity that has sufficient manpower, material, and fiscal resources to operate and maintain all water resources under its jurisdiction* [synthesis of several definitions; see APRP Report 49].. *All of the divisions support the water distribution process to ensure that water is delivered equitably, resulting in the various district water entities currently being merged to constitute a single entity referred to as an IWMD.*

Under the MWRI objective of equitable allocation of water resources, a series of activities were carried out to support the development of district water information systems. The effort focused on providing mechanism for the construction, and implementation of the information systems in support of water management decision making at the irrigation district level.

Recognizing the utilization of a framework that comprises satellite data, survey tools, and package of software supported initiation of a base for integrated water resource management. This paper will discuss the support of the district water information system comprising digital mapping as one of the steps toward the development of the district information system and supporting the implementation of IWRM. The use of such technologies offers extraordinary opportunities for producing information management tools that connect disparate, but indispensable, threads of spatial and non-spatial data across different information systems and management units. These tools create broader knowledge and understanding for decision makers at the district, directorate, and central levels.

PROBLEM DEFINITION

Currently, non-IWMDs collect data primarily for higher levels to make management decisions for them. For example, non-IWMDs do not prepare their water requirements and rotations. Instead, they are prescribed by directorates about three times a year.

Also, the availability, quality and completeness of the data sets at non-IWMD level are described as inconsistent, unmeasured or computed values, and they are based on unusually “round values. Basic data concerning physical system components, water resources quantity/quality, and water demands, is outdated and is available only on paper format.

The special relations and representation was not a requirement in non-IWMDs as no decision making was taking place. The non-IWMDs depended on either paper sketches or schematics that layout their physical system components. This also was found at the General Directorate level (decision making entity), but paper maps of scales 1:25000 and/or 1:50000 developed by the Egyptian Survey Authority (ESA) were broadly used. The problem is that these maps also are outdated (1950s) and the only way is to re-purchase the updated maps from the ESA and this is extremely expensive.

The basic data needed at the district is the served area and irrigable area. It is the base for water demand estimations. The area figures found at both district or directorates were outdated and undocumented or justified. These figures must be redefined and identified

The IWMDs now have the authority to make district-level management decisions. In order to that, the district managers require information in addition to data to provide a greater understanding and they need to receive this information timely. The knowledge required to support water management at the districts is inherently spatial and analytical in nature.

The Information system development activities were designed to introduce an electronic mapping system in order to provide the IWMDs with the capability of managing all of the data/information needed to support decentralized and integrated water management decisions at the district level.

DIGITAL MAPPING DEVELOPMENT ACTIVITIES

To introduce digital mapping as a component of the IWMD information system a mechanism comprises four tasks was adopted. The four tasks are:

1. Base map development Develop and install databases
2. Boundary delineation
3. Physical system delineation
4. Branch Canal (BC) boundary delineation

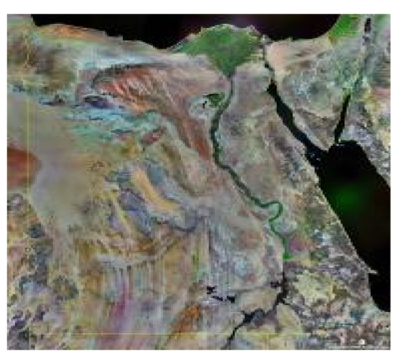

Figure 1. Egypt's Satellite Map

Base map development

A set of complete paper format 1:25000 maps scale and 1:50000 scale maps cover each district's area were purchased from the Egyptian Survey Authority (EGSA) and distributed among the integrated districts. The 1:25000 maps were scanned and geo-referenced using ARCGIS - (The Egypt Red Belt is the coordinate system used for the NSA paper maps. WGS1984 UTM 36 N is another commonly used coordinate system for Egypt) - and produced a geo-tiff format photos for each integrated district. A ministerial decree was issued to identify the new boundaries for the integrated districts taking into consideration the hydrological boundaries for each district. That in addition to using the satellite imagery (free NASA Landsat 7 ETM+).

Figure 2. NASA Landsat 7 ETM

Boundary delineation

For boundary identification, first the MWRI issues a decree to identify each district boundary in terms of northern, southern, eastern, and western boundaries. Afterwards, a team consists of the most knowledgeable staff of each district sketched the identified ministerial decree boundaries for their districts over a 1:25000 paper maps.

Figure 3. 1:25000 Paper Map Sketches

Those sketches were scanned and then by using ARCGIS on screen digitizing, a shape boundary file for each integrated district was created. The districts boundary shape files were send to the districts for verification and adjustment, then the final boundary shape files were produced and overlaid over a clipped satellite image and a 1:25000 compiled map.

Physical system delineation

The AutoCAD Map software was adopted rather than ARCGIS through this process for several reasons. First it is user friendly and commonly used software in Egypt among engineers, so previous experience is available among IWMDs' engineers. This is not true for ARCGIS. Second, it has the required features in terms of spatial map representation, link to attribute tables, map plotting, and shape files importing and exporting so its outputs can be exchanged with other software packages as needed.

On the AutoCAD MAP software environment, a process of identifying the geographic coordinate system and importing both the geo-referenced tiff 1:25000 maps and the clipped satellite was done as a first step to produce the district digital map including delineation of district boundaries and physical system components.
Several layers then were created in the AutoCAD file for each theme of the required themes to be added to the digital map of the integrated districts as follows:

- Canals/Canal Names Layers
- Drains/Drain Names Layers
- District Boundary Layer
- Water flow monitoring network sites Layer
- Water Quality monitoring network sites Layer
- Ground water Wells Layer
- Water structures (regulators, Weirs, Pump stations…etc.) Layers
- Branch Canal Water User Association Locations Layer
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Additional layers as required (as shown in the BC area layout section)

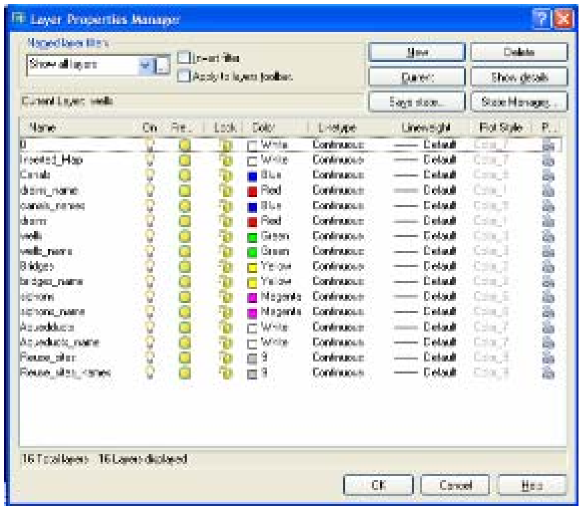


Figure 4. Developed Map Layers in AutoCad

Then the shape file for the boundary was imported as to the boundary layer. Using the technique of on screen digitizing, all the water ways (canals and drains) were digitized to the AutoCAD file in its corresponding layer. Using the GPS device all the locations of the water (quality and quantity) networks were surveyed downloaded to the district computers. Using the DNR Garmin software all stored data were converted to un-projected shape files and imported to the AutoCAD MAP file in their corresponded layers.

For groundwater wells locations, the ground water database itself has a feature to export its stored data in shape file format. These shape files were extracted from the groundwater database for each district and imported to the GW Layer in the districts AutoCAD MAP files.

A set of process were made to link the features digitized on the AutoCAD MAP file to an attribute table using the database connection impeded in the AutoCAD MAP and MS Access software.

A standard layout was set to all the digital maps produced for the 27 districts including legend, north direction, title bar, scale bar and frame.

Sample of the produced Integrated Districts digital maps is shown in the following figure.

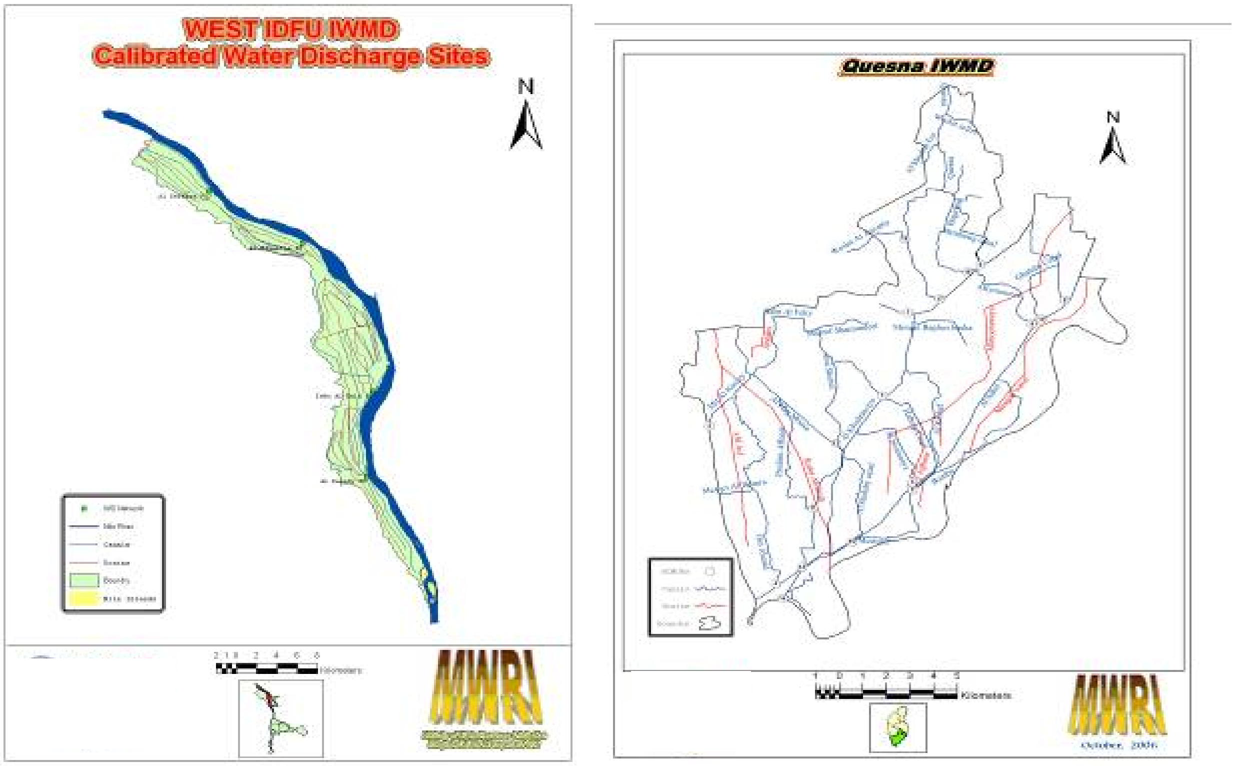


Figure 4. Developed Maps on ARCGIS

Branch Canal (BC) boundary delineation

The current set of area data which represent the area of each of the IWMDs. Values were computed by staff in each District at the time of District formation. However, staff in different Districts used different assumptions in making their estimates. The most important divergence in procedures used is between those Districts which estimated only the gross area within the designated boundaries of the District, and those which subtracted out certain non-agricultural lands such as urban areas, to obtain a net figure. It is not known which Districts fall into which category and, where deductions were made, what specific rules were used in making the deductions. These differences make the area data currently being used inconsistent and generally unsuitable for use. Estimates made using Landsat images indicates that in 16 of the 27 Districts, current area estimates differ from the Remote Sensing (RS) estimates of gross District area by more than ±10%.

Needed, in general, is a set of area figures produced using a standard set of rules and the most up-to-date geographic information available. The best available data will generally be remote sensing images. Maps which are more than a few years old will almost certainly under-represent the extent of urban area. More specifically, for monitoring and evaluation purposes, what is needed is a consistent set of values which represent the potential irrigable agricultural area within each District rather than the gross area enclosed by District boundaries.

There are two possible approaches to this problem, both based on analysis of satellite images. The first is to assess directly the cropped area during the baseline year (2004-5), i.e. "the green area" within the boundaries of each District. This area would then be treated as a constant value for the duration of the project. This approach has the advantage of simplicity. Its drawbacks are (a) green area may actually change from year to year or season to season, when what is needed is a fixed value of "irrigable" area, (b) this value will not include "irrigable but currently fallow" land, (c) this value may be perceived as a variable rather than the required parameter (one which characterizes the district for a longer period of time), (d) it will not include areas which are indeterminate or difficult to classify.

An alternative approach, the deduction method, begins with the gross area of the District, as measured on RS images, and deducts three categories of known non-agricultural land, (1) open water, (2) urban and residential areas, and (3) wasteland. This approach offsets many of the drawbacks mentioned above for the "green areas" approach. In particular these net values (a) change only slowly and incrementally as urban areas expand, (b) are more closely related to the "District area" values currently accepted by the Ministry and are thus likely to be more acceptable within the Ministry, and (c) include fallow but irrigable areas.

To overcome that problem and to get an actual figure for the irrigable area served per each district. A practical approach was carried out based on extensive filed survey rather than RS images that identifies the layout and calculates the irrigable area served by each branch canal.

This approach is presented as follows:

Rational For each branch canal, the area served is defined as the total irrigable land that (land usually supplied with water from the branch canal for crop production). Fallow lands (i.e. lands not irrigated this year or this season but was irrigated the year before) should be included.

This branch canal served area may differ, (a) significantly from the boundary area (area within boundaries) which may include urban, industrial and other non-agricultural areas, (b) slightly from the net agricultural area, because of the way it will be measured (branch canals, mesqas, minor drains and roads may get included), (c) significantly in Upper Egypt from the unauthorized culrivated areas, as new lands are expanded and irrigated unofficially on the desert fringes.

Objective To layout and calculate, with reliable accuracy, the irrigable area served by a branch canal. This will help improve the calculation of water needs, and the allocation of water resources. Ultimately this will also improve the matching between irrigation demand and supply.

Equipment needed GPS Device and pre-produced districts digital maps

Methodology

Preparation (Before):

- preparation/drawing initial draft sketches of each BC boundary from district digital map, or the scanned map (1:25000), or paper based maps by district knowledgeable staff.
- Identifying landmarks on each BC initial boundary using the digital maps and tabulating its coordinates.
- Feeding the BC landmarks coordinates in the GPS to be as a guide during the field work.

Field work (During):

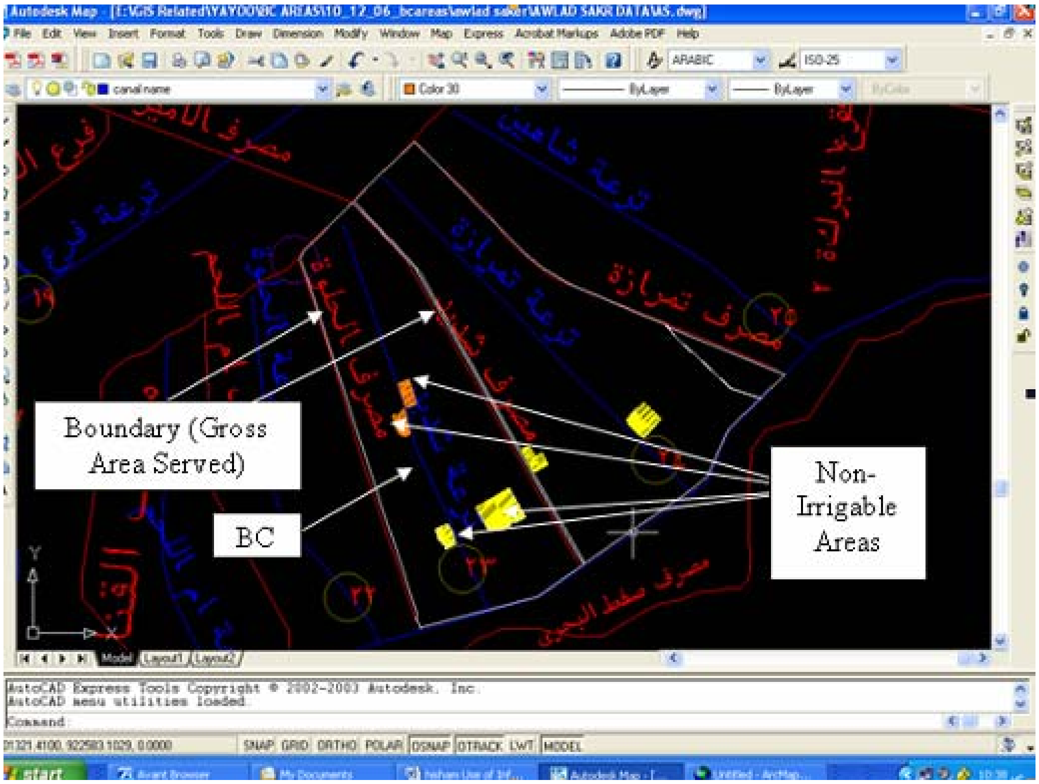
- Checking the boundaries of the BC served areas and starting the GPS tracking process around BC boundary in the field.
- Verifying location during tracking process using identified landmarks.
- Adjusting BC track in the filed by asking farmers from which branch canal their plot is irrigated when there is a doubt.
- Saving the BC track on GPS device.
- Using the Area calculator function of the GPS a first estimate of the area served can be identified.

Office work (After):

- Connecting the GPS device to district computer.
- Setting the map projection correctly.
- Importing the tracks to AutoCAD Map from the GPS using DNR Garmin software and saving these tracks as shapefiles.
- Importing and overlaying the tracks on the 1/25,000 base map on the screen, checking that the tracks are correctly aligned on the map, i.e. that they match known landmarks.
- Using the ‘list’ command on AutoCAD Map to calculate the boundary area. This should give the BC gross area served.
- Proceeding similarly to evaluate the non-irrigable areas by GPS tracking and calculate its area.
- Deducting calculated non-irrigable areas from the calculated BC gross area identifying the BC net irrigable area.
- Using the clipped satellite image or Google Earth image or even the GPS device the integrated districts’ team determinated the non-irrigable areas.Then they tabulate this data in the following form:
-

Feeder canal	Branch canal	Main boundaries	Gross area (fed)	Non-agricultural areas (fed)	Net irrigable area (fed)

The previous process started in January 2007 and planned to be finished within a seven-month period.



Feeder canal	Branch canal	Main boundaries	Gross area (fed)	Non-agricultural areas (fed)	Net irrigable area (fed)
Deffan	Sheded	Mosque at village 8 Al Hamra	1693.47	65.54(residential) + 29.16 (water way)	1598.77

Figure 5. Sample of Outputs

SUMMARY

- The presented task when accomplished it will provide a detailed digital map up to the branch canal level within each district for the first time in Egypt.
- The presented task when accomplished it will have the potential to permanently change how the IWMDs and directorates manage, use, and communicate their water resources data in the near future.
- A digital mapping unit is needed to be established with GIS computer hardware and software and GPS receivers, plus the scanned maps (1:25,000) and Landsat images at each of the MWRI directorates.

LESSONS LEARNED AND RECOMMENDATIONS

Identification of lessons learned from any endeavor is extremely valuable, and in this instance, essential considering more advanced information system activities will be carried out in the future. The following lessons learned and recommendations are the result of an attempt to objectively identify items worthy of consideration when implementing and integrating information systems at the districts and directorates.

Databases Specific databases may be introduced and standardized, based on the IWMD requirements, such as the water resources inventory, water quality, and groundwater. These databases when introduced can be linked to the digital map of the district to support decision making process at this level.

Area Data The comparison between the GIS and IWMD area estimates varied extremely (88 – 269%). There is a need to have a set of area figures produced using a standard set of rules and the latest land cover data available.

The MWRI should support the process of calculating/measuring the total irrigable agricultural area in each IWMD (i.e., Green area and deduction methods with satellite imagery, 1:2,500 paper maps with a planimeter, and field survey with GPS units) and compare it with MALR area figures.

Digital Mapping For ease of data integration at the directorates, it is necessary to re-project all the map layers using the same projection. A map projection of WGS 1984, UTM 36N is recommended because the re-projected map layers in UTM can be: (1) visually geo-referenced and verified using the available Landsat 7 imagery, which has the same map projection; and (2) used to perform complex vector-raster GIS analyses including but not limited to determination of irrigable areas for the 27 IWMDs.

To ensure high quality work, carrying out data quality assurance and quality control is recommended to show that (1) the shared boundaries among the IWMDs within a directorate are matched perfectly; (2) canals in the irrigation system network are linked by vertex; and (3) drains in the network are also linked by vertex. Additionally, the IWMD mapping staff will need to verify the location and alignment of each canal and drain with GPS points or tracks.

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MODERNIZATION IMPROVEMENTS — OPTIONS, DECISIONS AND IMPLEMENTATION AT OAKDALE IRRIGATION DISTRICT

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ABSTRACT

Facing a magnitude of issues including failing infrastructure, water rights challenges, and low water use efficiency, the Oakdale Irrigation District (OID) Board of Directors voted in 2004 to develop a Water Resource Plan (WRP) to guide the District for the next 20 years. The WRP was finalized and adopted by the Board in November 2005 with the five following goals stated:

1. Provide long-term protection to OID's water rights
2. Address federal, state and local water challenges
3. Rebuild/modernize an outdated system to meet changing customer needs
4. Develop affordable ways to finance improvements
5. Involve the public in the planning process

All of the stated goals are interrelated and progress on one has ancillary benefits to others. This paper will predominately focus on the rebuilding and modernizing efforts the OID has implemented since the adoption of the WRP, with major focus on the modernization of the District's diversion structures. This paper will discuss the many options available for modernization, the decision process on the path selected, and the implementation of projects to achieve modernization.

INTRODUCTION

The Oakdale Irrigation District (OID) was organized on November 1, 1909, under the Wright Act. In July 1910, the OID and the South San Joaquin Irrigation District purchased an established ditch system known as the Tulloch System. The Tulloch System had been developed in the 1880s by Charles H. Tulloch, primarily serving the Knights Ferry community with diverted water from the Stanislaus River. Since that time the OID has expanded its service area to encompass approximately 72,345 acres, of which an estimated 55,000 acres are irrigated to produce a variety of agricultural crops, largely pasture, corn (silage), and rice.

The District's development since 1909 can be separated into three distinct chapters. Those three chapters are characterized by significant events that took place that forever changed the Oakdale community and its agricultural development. The first chapter is obviously the organization of the District at the turn of the century, the second chapter was the formation of the Tri-Dam Project, and the third chapter is beginning to be

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written. In the first chapter the District was rapidly expanding the service area and infrastructure needed to meet a growing irrigation demand. In their haste the District failed to invest in the essential infrastructure required to provide reliable irrigation supplies needed to grow more profitable crops in the region. During the early years, most farmers grew oats and other grain crops. Only the most entrepreneurial of farmers tried to grow anything else due to the likelihood that the water supply would dry up by late summer.

The second chapter of the District was aimed at firming up supply reliability and began when the District's Chief Engineer, R.E. Hartley, started expeditions in the Sierra Nevada Mountains along the Stanislaus River. Mr. Hartley spent many years packing into the mountains east of Oakdale looking for ideal reservoir sites to harness the mighty runoff from the Stanislaus River. Three sites were found and soon the District started looking for ways to finance the construction of the "Tri-Dam" Project. The financing came by way of the Pacific Gas and Electric Company whom would pay for the construction of the dams in exchange for a long term contract for the ancillary benefit of the hydropower generated at the sites. The District agreed and the dams were built. However the construction of the dams came at a price. So much effort was placed into the construction and operation of the dams that the District lost sight of the operation and maintenance of the irrigation distribution system.

Nearing the turn of the 21st century, the District's delivery system was in a state of disrepair and the District's finances were barely covering operational costs. In conjunction with these shortcomings, turnover at the Board and Managerial level left little room for optimism and certainly didn't contribute to improving the District's financial future. Looking for any way to generate revenues without increasing the all too politically volatile water rates, the Board of Directors approved a water transfer that would supply the much needed revenue stream. Soon after this first water transfer, the District's long term contract with Pacific Gas and Electric was set to expire. The renegotiated hydropower contract would provide additional revenues needed to address myriad infrastructure issues. However, before the District could move forward a plan was needed.

In 2004, with a new Board of Directors and a new General Manager, the District voted to develop a Water Resources Plan (WRP) that would formulate the rebirth of the District and provide guidance for the District over the next 20 years. The WRP was finalized and adopted by the Board in November 2005 with the five following goals stated:

1. Provide long-term protection to OID's water rights
2. Address federal, state and local water challenges
3. Rebuild/modernize an outdated system to meet changing customer needs
4. Develop affordable ways to finance improvements
5. Involve the public in the planning process

All of the stated goals are interrelated and progress on one has ancillary benefits to others. This paper will predominately focus on the rebuilding and modernizing efforts the OID has implemented since the adoption of the WRP, with major focus on the modernization of the District's diversion structures.

OPTIONS FOR MODERNIZATION

Infrastructure replacement is a given and is long overdue for the District. However, is infrastructure replacement as simple as just reinstalling the existing facilities or is it as complex as redesigning the entire distribution system? For the Oakdale Irrigation District the answer is somewhere in-between. When the distribution system was originally built in the 1900's it was designed to supply water in large flow rates for large parcels (greater than 160 acres). However, a century's worth of development has occurred and large parcels are no longer the norm. Instead, the District is littered with small parcels (less than 10 acres) and the cropping trends in the District tend to be highly random. So what are the options available to a District looking to replace existing infrastructure with new infrastructure capable of meeting the needs of an ever-changing customer base for at least the next 50 years? For the purpose of this paper, what are the specific options available for diversion structures?

Most of the existing diversion structures in the District utilize a combination of a square shop gate and an afterthought over-pour weir. The square shop gate is an in-house fabricated steel sluice gate with a square opening. The thought behind the installation of these gates was that they were inexpensive, easy to construct, and measurement was easily achieved by using a differential head equation. However as depicted in Figures 1 and 2 presented below, most of the shop gates were undersized or operated infrequently and over toping of the upstream canal section occurred often. The solution was to add over-pour "weirs" as shown in Figures 1 and 2. The result of the non-standard and poorly constructed over-pour weirs negates all of the benefits of the square shop gates.

Figure 1. Upstream View of Typical OID Diversion Structure

Figure 2. Downstream View of Typical OID Diversion Structure

Any option for replacement of these diversion structures needed to meet four basic criteria: 1) Automatic control of the upstream pool elevation; 2) Flow control with flow measurement; 3) Affordability of construction and maintenance; and 4) Flexibility for future demands and operating scenarios. Based on these criteria the District began to evaluate various options and combinations of the following devices: long crested weirs, Replogle flumes, overshot gates, sluice gates, propeller flow meters, magnetic flow meters, etc. The list of possible designs is vast; however, a few obvious alternatives fell out rather quickly.

MODERNIZATION DECISIONS

Obviously there is no quick and easy solution and each option or combination of options has inherent consequences or shortfalls. In order to evaluate the different options available, the District developed a matrix based on the previously stated criteria. The District used the matrix to evaluate four possible configurations. The four selected configurations that could possibly be used to achieve the Districts' desires are presented below:

1. Long Crested Weir for Upstream Level Control with Automated Sluice gates at the bifurcation. Flow measurement would be achieved downstream with a Replogle Flume.
2. ITRC Flap Gate for Upstream Level Control with Automated Sluice gates at the bifurcation. Flow Measurement would be achieved downstream with a Replogle Flume.
3. A series of Sluice Gates for Upstream Level Control and Flow Control on one of the Canal Headings. Flow measurement would be estimated at the sluice gates.
4. Overshot Drop Leaf Gate for Upstream Level Control and/or Flow Control. Flow measurement would be achieved at the drop leaf gate.

The four configurations were ranked in the matrix that was developed. The configuration that is most favorable for a given category was given a ranking of 1; the least desirable configuration was assigned a ranking of 4. The evaluation and matrix is presented below in Table 1:

Table 1. Configuration Matrix for Evaluation

Configuration	Consistent U/S Level Control	Flow Control & Flow Measurement	Affordability	Flexibility	Average Ranking
Long Crested Weir	1	2	4	3	2.5
ITRC Flap Gate	2	3	1	4	2.5
Sluice Gates	4	4	3	2	3.25
Drop Leaf Gate	2	1	2	1	1.5

As the matrix indicates the Drop Leaf Gate configuration scored the best based on the design criteria for Oakdale Irrigation District. The benefits of the Drop Leaf Gate are numerous but the key element was flexibility and affordability. The Drop Leaf Gate allows the user to configure and operate the gates in a number of modes, such as flow control, level control, or gate position. This flexibility is essential in order to meet current and future demands.

While all the options could achieve the current or future demands, it is the ability to meet both current and future needs without unreasonable burdens, financial or otherwise that is most important. For example, the District has a particular Lateral Service Area in which the current irrigated acreage is approximately 5,000 acres. During the 20-year planning horizon the District anticipates that the irrigated acreage in this particular service area will increase by 3,500 acres, a 75 percent increase. Consequently, the flow required to meet peak daily evapotranspiration is significantly greater than the current demand. If the District were to select a long crested weir for level control, with its inherent fixed crest elevation, what is the effect on weir length given the two operating scenarios? A longer weir length under reduced flow conditions makes flow control difficult at the canal headings due to the narrow operating range in the upstream pool. The advantage of a drop leaf gate in this scenario is that there is no fixed crest elevation and the gate can be sized for both current and future demand. It is for this flexibility that drop leaf gates are preferable. However, flexibility must always be balanced with affordability.

For Oakdale Irrigation District, like many other irrigation and water districts in the central valley of California, the locations of these diversion structures are often remote and acquisition of a reliable power source to energize a modernization project can be financially unreasonable. Based on unfavorable District experience, DC power for motor actuated slide gates was not a desirable option. With the high cost to bring power to these remote sites and bad experiences with battery powered slide gates, the District was looking for an affordable alternative and the drop leaf gate provided such an alternative.

MODERNIZATION IMPLEMENTATION

Once the District had settled on the drop leaf gate configuration, selection of a manufacturer and specific product needed to occur. The District evaluated the few established products available in the market and selected the Rubicon FlumeGate as the most appropriate for installation. One of the primary reasons for the selection of the FlumeGate was that the product was a turnkey package. Essentially the gates could be dropped into place and functional within a few hours. This is especially true given that the gates are supplied with solar panels; making the remote location power issue null. An example of the modernization efforts are depicted in the before and after photographs from a recently completed project as shown in Figures 3 and 4 below.

Figure 3. OID Diversion Structure Pre-Modernization

Figure 4. OID Diversion Structure - Post Rubicon Gate Installation

Moreover, the Rubicon gates are Supervisory Control and Data Acquisition (SCADA) ready for a variety of protocols. Prior to selecting the Rubicon gates, the District had just recently upgraded the Human Machine Interface package to Control Microsystems ClearSCADA and it was important to ensure that the Drop Leaf Gate that was selected would be capable of working in the modbus environment. Rubicon's predominant protocol is MDLC, however Rubicon was able to supply the modbus drivers and the integration into the District's SCADA system was nearly seamless. The District continues to find small edits that are necessary in the program; however the edits have been cosmetic and not functional issues.

To date the District has installed 18 Rubicon gates with plans for an additional 20 sites to be installed over the next five years. The District has had great success thus far with the Rubicon gate configuration and additional benefits have been realized that were not anticipated. For example, the District utilizes an aquatic herbicide to control vegetation growth in the canals. The District must ensure that while the herbicide is being used that none of the treated water is discharged outside the intended treatment area. Having the ability/flexibility to operate the Rubicon gates in a variety of modes such as flow control or upstream level control makes the herbicide applications easier to manage. Moreover, the ability to accurately measure the flow rates during these applications allows the District to reduce cost by applying the herbicide in exact concentrations dependent upon the stage of vegetative growth. As stated previously, this type of flexibility is vitally important for the District to maintain into the future. Agricultural and economic market conditions are highly variable and the District aims to build in the needed flexibility to meet the needs of a dynamic customer base.

CONCLUSION

In conclusion, the District spent a lot of time identifying potential alternatives that would meet the needs of the District. The District believes that the selection of the Rubicon gate has served well so far. However, there are some unknowns still looming, specifically long term maintenance and gate longevity. The success of the modernization effort cannot be determined yet. One of the outlaying issues is. With that said, the District has been very satisfied with the gate operations and the customer support provided by the manufacturer. The District is hopeful and confident that in time the modernization efforts will be deemed a success.

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IDENTIFYING OPPORTUNITIES FOR DISTRICT-WIDE WATER SAVINGS USING REMOTE SENSING TECHNOLOGY

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R. Skaggs[4]

ABSTRACT

Irrigated agriculture is the largest water user in New Mexico; in southern New Mexico's Lower Rio Grande region, agriculture uses about one million acre-feet of water each year. Previous research has estimated that the average irrigation efficiency in the area is 44%. This relatively low aggregate efficiency indicates a large potential for water savings from agriculture. In order to determine the potential water savings, the amount of water depleted by crop evapotranspiration (ET) in the Mesilla Valley section of the EBID was estimated using satellite information and ground-level measurements to calculate plant consumptive water use on scales ranging from individual farms to the larger watershed.

Two areas of potential water savings were evaluated using the satellite-generated consumptive use information: 1) potential water saving at the farm level and 2) potential water saving at the district level.

This study found that the majority of farms in the study region were growing crops under deficit irrigation conditions. Therefore, irrigation improvements at the farm-level are likely to increase both yields and water depletion.

Potential water savings at the district level were evaluated by comparing the total volume of water diverted for irrigation versus aggregate ET. From the satellite-generated ET data, district-level efficiency was determined to be 55% in 2002 (a full allocation year). Thus, there appears to be a potential for improving district-level efficiency. This can be accomplished by using regional ET depletion values to plan water releases from the reservoir and improve the diversion and distribution within the canal networks.

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INTRODUCTION

Irrigated agriculture is the largest water user in New Mexico and is responsible for 90% of depletion. In southern New Mexico's Lower Rio Grande region, about one million acre-feet of water are used for agriculture each year. Previous research has estimated the average district-wide irrigation efficiency in the Elephant Butte Irrigation District to be 44% (Magallanez and Samani 2001). This relatively low district-wide efficiency appears to indicate a large potential for water savings from agriculture. The conventional wisdom in the study region and in many other irrigated areas is that reduced consumptive use by agriculture through investments in on-farm technology and changes in on-farm water management practices will increase system-wide efficiencies and result in large quantities of water available to other users (e.g., municipal, industrial, environmental, etc). In order to determine the amount of potential water savings by agricultural water users, the amount of water depleted by crop evapotranspiration (ET) must first be estimated. ET is the true depletion from the hydrologic system which cannot be reused (other than a small amount which is returned in the form of precipitation). Any water applied to crops but not depleted has the potential to be recycled, reused, or transferred to other users (although quality factors, timing issues, and spatial limitations may reduce the potential).

Various methods have been developed for estimating ET, including the popular use of crop coefficients and climatic parameters. One commonly used method of assessing ET is the eddy covariance technique, which estimates real time ET in the field. Estimates of ET also can be made through soil moisture monitoring or lysimeters. While these methods can provide point measurements of ET, they cannot cost-effectively account for broad-scale, field-level spatial variability of ET under real-world growing conditions. However, due to recent advances in remote sensing technology, basin-wide, field-level ET accounting is now both technically and financially feasible. Remote sensing has made it possible to combine ground measurement of ET with remotely-sensed satellite data and ground level climatological data to arrive at regional ET values. This combination of ground-level and remotely-sensed data provides the most advanced and cost-effective approach to estimating ET over large areas with non-uniform, field-level crop production conditions. As a result of remote sensing, it is now possible to comprehensively assess basin-wide depletion as a result of crop production. Remotely-sensed information on crop coefficients and crop consumptive use can be used to increase water management efficiency, enhance water conservation, and increase water use accountability.

METHODOLOGY

A remote sensing technology, the Regional Evapotranspiration Estimation Model or REEM, developed at New Mexico State University (Samani et al. 2005, 2006, 2007) was used in combination with ground measurements to determine daily ET depletion by agriculture in the Mesilla Valley section of southern New Mexico's Elephant Butte Irrigation District. LandSat images for 2002 (12 images) and 2003 (10 images) were processed to develop ET and crop coefficient (Kc) maps for the Mesilla Valley. The years 2002 and 2003 were selected because 2002 was a typical full allotment year where the farmers received three acre-ft per acre per year of water and 2003 was a dry year where the farmers received only nine inches of surface water. REEM results led to the development of daily ET maps for agricultural crops and estimation of potential water savings at both the farm and district levels.

The REEM model was validated on a daily basis using actual measurements of ET from data collected by eddy covariance flux towers located in a pecan field in the Mesilla Valley (latitude 32.18 N and longitude 106.74 W; elevation above sea level 1,144 m). Using satellite images from clear days, maps of ET and Kc were generated. The 2002 and 2003 comparisons of measured and REEM-predicted ET for a mature pecan orchard are shown in figure 1 and figure 2. REEM was also used to predict daily ET by alfalfa, cotton, and other minor crops. Pecans, alfalfa, and cotton account for approximately 75-80% of the irrigated acreage in the study region.

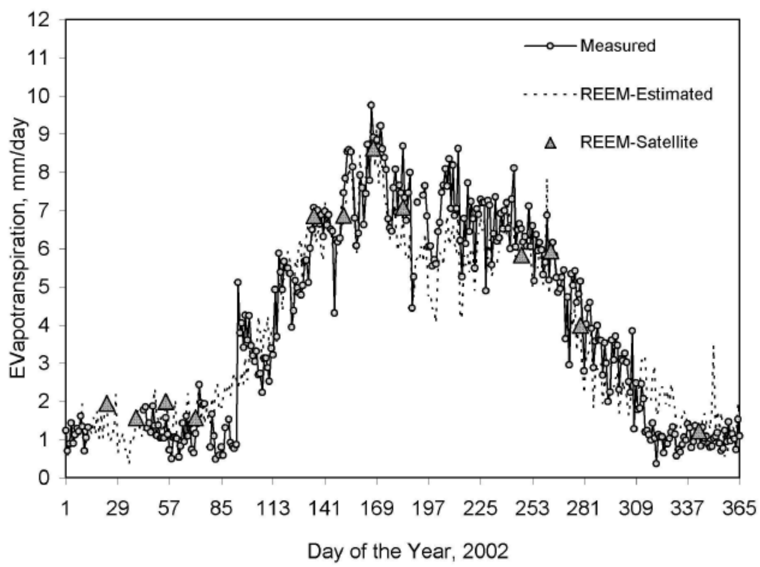

Figure 1. Comparison of daily measured and predicted pecan ET for 2002.

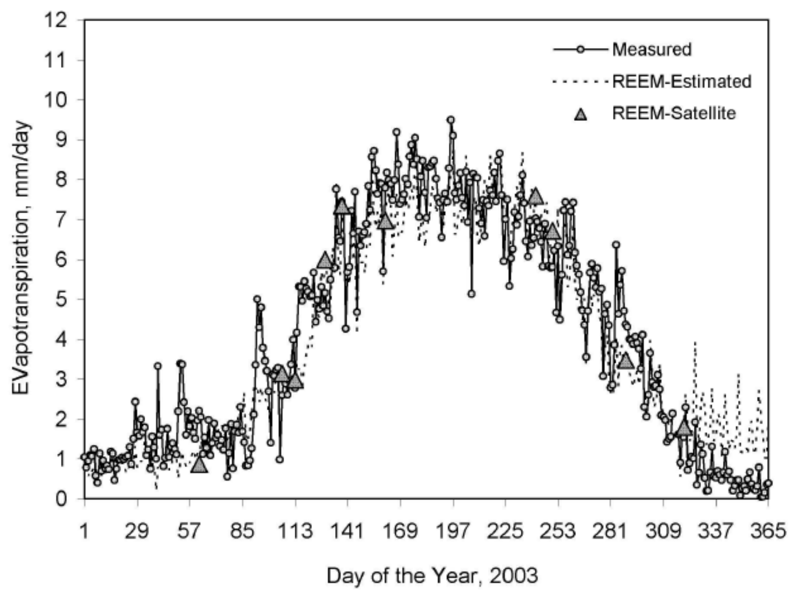

Figure 2. Comparison of daily measured and predicted pecan ET for 2003.

Daily maps of ET were then integrated to develop monthly and yearly values of ET for each field in the study region. Figure 3 and figure 4 show annual ET maps for 2002 and 2003. The ET values were calculated for each pixel 30 m by 30 m (98 x 98 ft) pixel. Individual fields were delineated using the 2005 DOQQ (Digital Orthophoto Quarter Quadrangle) maps and superimposed on the ET maps. Average ET for each delineated field was calculated by summing up the individual volumetric water use for each pixel and dividing it by the area of each field. The final satellite-generated consumptive use results were used to evaluate two areas of potential water savings: 1) potential water saving at the farm level and 2) potential water saving on the district level.

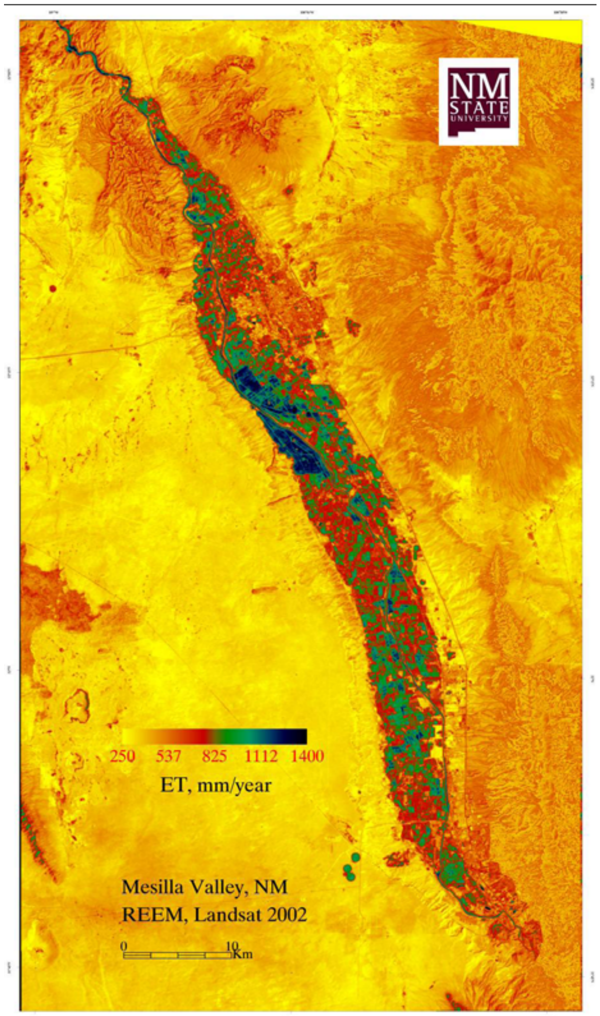

Figure 3. Annual ET for 2002, Mesilla Valley, NM.

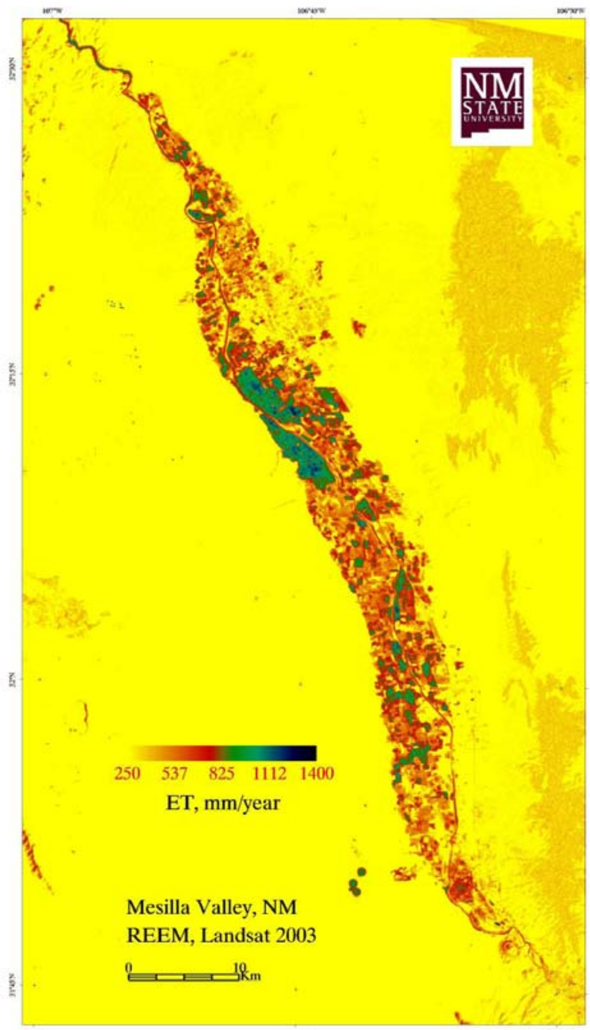

Figure 4. Annual ET for 2003, Mesilla Valley, NM.

POTENTIAL WATER SAVINGS AT THE FARM LEVEL

It is conventionally believed that changes in on-farm water management have the potential to result in water savings and reduce the amount of water "wasted" by agriculture, thus releasing water to other users (both in time and space). However, scatter plots for pecan and alfalfa fields in the study region show that the majority of the fields are under-irrigated and are being managed under deficit irrigation conditions relative to potential ET and potential yields. For both pecans and alfalfa, reduced ET is strongly correlated with reduced yields.

Deficit irrigation on Mesilla Valley farms is the result of several factors, including:

- Lack of sufficient ground water to supplement surface water supplies on individual farms;
- Limited or no access to ground water of adequate quality on many farms;

- Lack of knowledge of crop water consumptive use and associated benefits of irrigating to meet that demand;
- Inability of existing canal system to deliver surface water in a timely manner;
- Poor irrigation practices (e.g., non-uniformity of water application) and soil variability;
- Low volume of inflow and poor on-farm water distribution systems;
- Issues related to agronomic practices (e.g., alfalfa flood irrigation and harvest operations, etc.).

Given the high incidence of deficit irrigation in the study region, improvements in irrigation system design, modernized technology, or finely-tuned on-farm scheduling are likely to increase both yields and depletion of water. These results are strongly at odds with many of the prevailing assumptions regarding agricultural irrigation in the Mesilla Valley. It is often assumed that agricultural irrigators regularly overwater, and are thus creating opportunities for water savings with improved irrigation technology and practices. However, given the current prevalence of deficit irrigation, improvements in irrigation scheduling or modernization of on-farm irrigation technology are likely to compromise the release of water from agriculture for other uses. Thus, the real potential savings of water within this region appear to be at the district level.

POTENTIAL WATER SAVINGS AT THE DISTRICT LEVEL

Potential water savings at the district level were evaluated by comparing the total volume of water diverted for irrigation versus aggregate REEM-estimated ET in the study region. The REEM-predicted ET in the Mesilla Valley for the years 2002 and 2003 were 265,554 and 205,207 acre-feet, respectively. Efficiency was calculated based on the net diversion and rainfall (which was 7.4 inches during 2002 and 4.7 inches in 2003). Total net diversion was calculated by subtracting inflow at the Leasburg Dam (beginning of the Mesilla Valley) from the outflow at Courchesne Bridge (at the end of the Mesilla Valley).

The total EBID Rio Grande diversion for 2002 and 2003 in the Mesilla Valley was about 421,000 and 163,000 acre-feet, respectively. Accounting for the rainfall, the total diversions for 2002 and 2003 were about 482,000 and 202,000 acre-feet (diversion + rainfall). Figure 5 and figure 6 compare annual ET versus diversion in the Mesilla Valley section of the EBID for 2002 and 2003. An efficiency of 55% ((district ET / (rainfall + diversion)) was estimated for 2002, and 101% was estimated for 2003. The 2003 high efficiency is due to drought-induced ground water pumping which increased the depletion relative to diversion. Depletion from ground water was estimated to be 30,600 acre-feet in 2002 (a full allocation year) and 74,000 acre-feet in 2003 (a partial allocation year). Ground water depletion was estimated by subtracting net surface water inflow into the Mesilla Valley (rainfall included) from REEM-estimated depletion in the region. There are no actual measured data available regarding ground water depletion in this region against which to compare this estimate.

The results presented in figures 5 and 6 illustrate that, on the district level, there is a potential for improving basin-wide irrigation efficiency, particularly in full allocation years. The disparity between REEM-estimated ET and actual diversion shows that for a full allocation year there was a potential savings of approximately 150,000 acre-feet. Examination of the water budget and downstream delivery obligations shows that the district spilled approximately 140,000 acre-feet of water. The disparity between diversion and depletion illustrated throughout 2002 and in several months of 2003 could be reduced by using regional ET depletion values to forecast and plan water releases from the reservoir and improve surface water distribution within the canal networks.

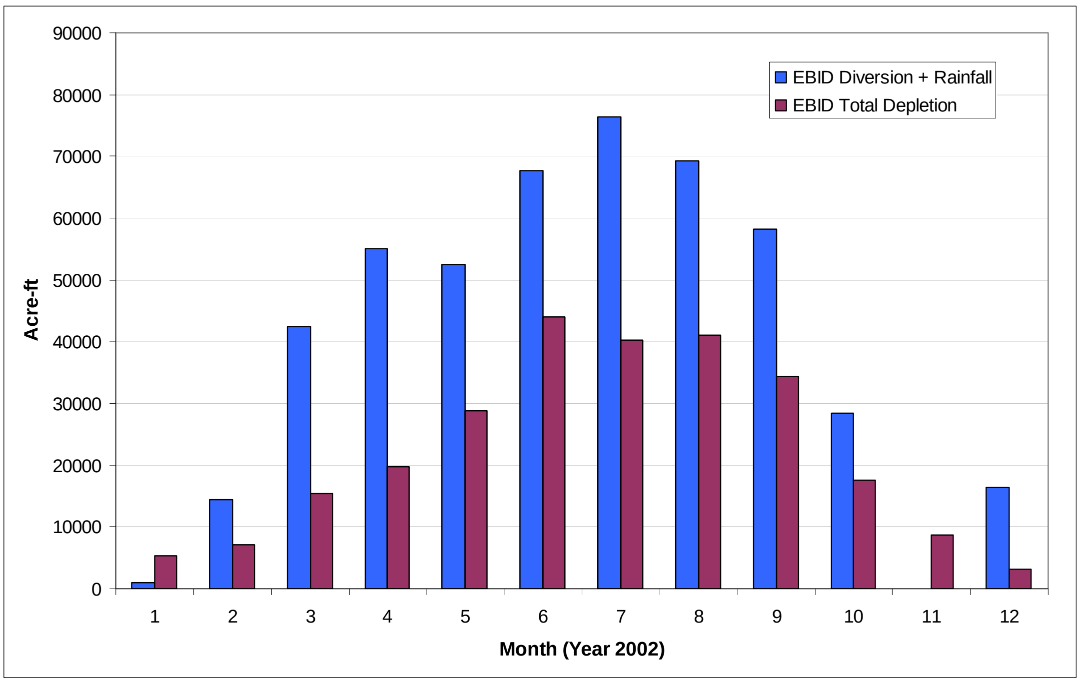

Figure 5. Comparison of total depletion and EBID surface water diversion + rainfall, 2002.

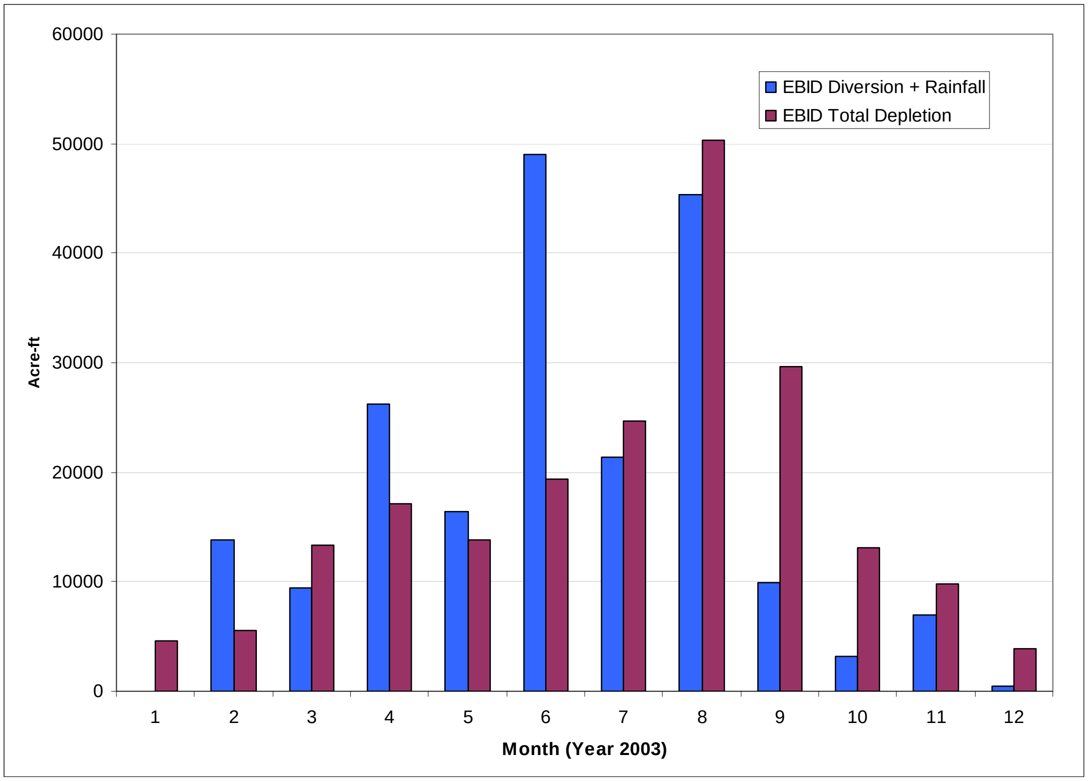

Figure 6. Comparison of total depletion and EBID surface water diversion + rainfall, 2003.

CONCLUSIONS AND RECOMMENDATIONS

The results of this research indicated that farms in the Mesilla Valley are generally under-irrigated, and thus under-achieving with respect to yields and gross financial returns. There is a potential to improve farm-level water management, increase productivity, and enhance water use efficiency in the study region through measures such as accurate irrigation scheduling and improved irrigation technology. However, these changes would likely improve economic returns to agriculture in the Mesilla Valley at the expense of increased consumptive use by agriculture – rather than create opportunities to release water from agriculture to other users. This research also found that the potential for water savings more likely exists at the district-level, if the district develops the ability to manage diversions in accordance with real-time crop consumptive use needs. However, if current levels of upstream district-wide efficiency have created and guarantee downstream water users' supplies, then changes in district-level management could have serious consequences for the downstream users.

The results presented here illustrate the potential for field-level remotely-sensed ET estimates to be extended to district-wide management. The model and methodology presented here can be used by water resource planners, managers, engineers, farmers, and others to estimate water use by crops as well as by urban or natural landscapes. The ultimate objectives of the model and methodology are more efficient water management, water conservation, and increased water use accountability – objectives which satellite data can help achieve both comprehensively and cost-effectively.

ACKNOWLEDGEMENTS

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HYDRAULIC MODEL INVESTIGATION OF DELTA-MENDOTA CANAL

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ABSTRACT

The flow capacity of the Delta-Mendota Canal (DMC) from the San Francisco Bay Delta to the O'Neill Forebay is not capable of delivering the original design flow capacity. This restriction is the result of inadequate flow capacity designed into the original canal sections, altered delivery patterns impacting the original telescoping design flow requirements, freeboard constraints, and possible ground subsidence over the past 60 years. The Bureau of Reclamation is considering various alternatives to compensate for these capacity limitations, including the construction of an Intertie between the DMC and the California Aqueduct. To determine the hydraulic feasibility of these alternatives, the capacity of the existing conveyance system and the areas where conveyance restrictions occur were investigated. A one-dimensional hydraulic model, HEC-RAS, was developed and calibrated to the upper 70 miles of the canal. The model has about 1,000 cross sections, and includes 13 check structures, 9 inverted siphons and inline culverts, and numerous bridges and other crossings. During model calibration, a number of issues were encountered that form the basis of the discussion in this paper. They include examining the tidal influence on pumped flows into the canals from the Delta area at Tracy, the resolution of a datum problem between the main canal and the O'Neill Forebay Canal, and an examination of the "sluice gate" coefficients at the various checks in the system.

INTRODUCTION

Construction of the Delta-Mendota Canal (DMC) in the northern part of California's Central valley was started in 1946 and was completed in 1952. The Jones Pumping Plant (JPP) lifts water from the San Joaquin River, and pumps it into the DMC, where it flows southward for approximately 117 miles before discharging back to the San Joaquin River at the Mendota Pool. Deliveries to permitted users are provided at turnouts along the canal.

The DMC was built in sections, with an initial design capacity of 4,600 cfs that progressively decreases throughout its length to 3,200 cfs as it discharges into the Mendota Pool. The study area for the hydraulic model and evaluation of the design objectives evaluated is just downstream of the discharge from the JPP (MP 3.50) to Check Structure 13 (MP 70.01) (Figure 1). It also includes the O'Neill Forebay Canal (OFC), located at MP 69.25. From the DMC, the OFC heads west for 0.47 miles and

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terminates at the O'Neill Pump/Generating Plant located at the base of the O'Neill Dam and O'Neill Forebay. Table 1 lists the original design parameters used to design each section. Canal sections were sized using Kutter's equation with n=0.014. This corresponds to *n*=0.0138 from Mannings equation.

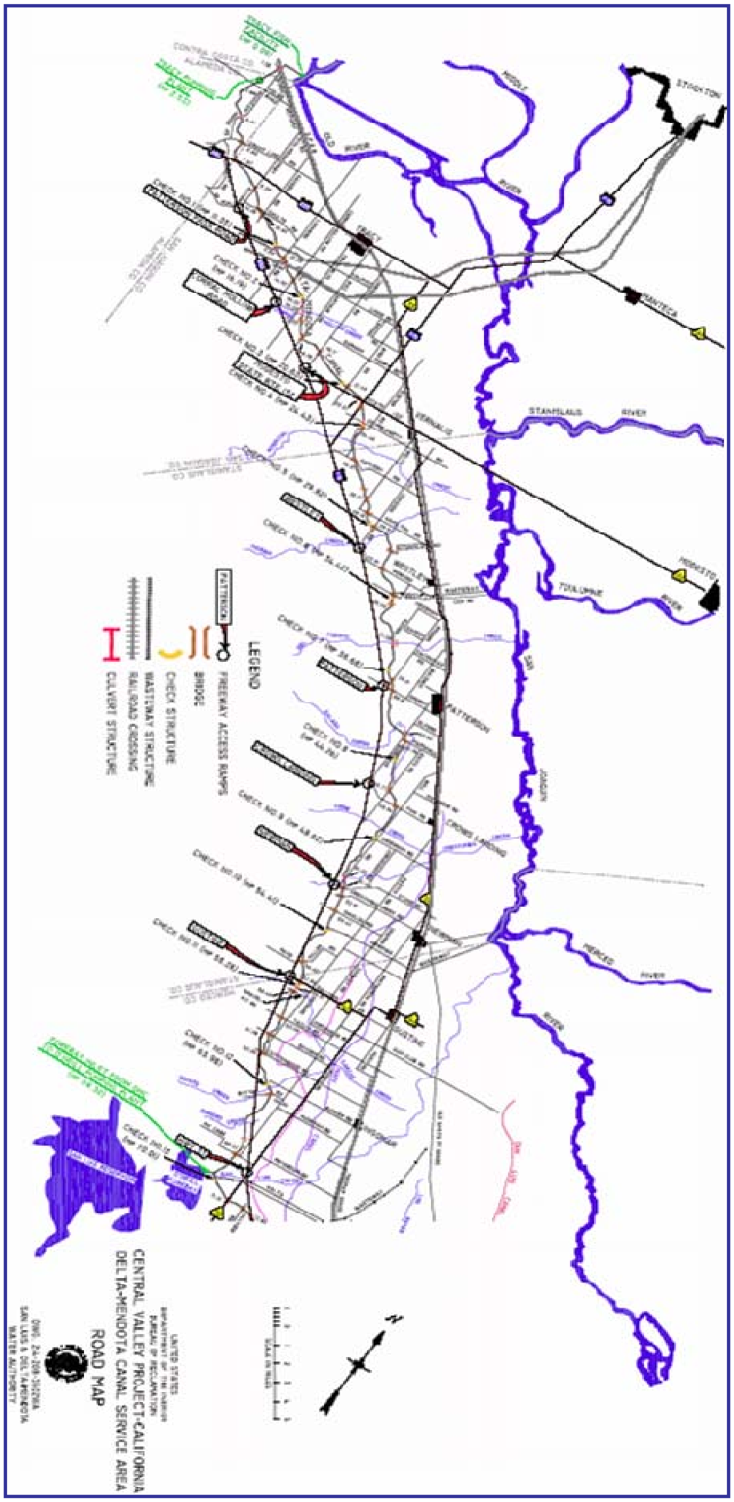

Figure 1. Study Area

Table 1. Cross Sectional Properties and Design Flow

Canal Section	Distance Mile from 0.00	b (feet)	<1965 h (ft)	>1965 h (ft)	1965 Lining Raise (in)	Side slope (ft / ft)	Design Flow "Q" (cfs)	Bed slope S_0 (ft/ft)
3	3.50 to 13.66	48	18.08	19.58	18	1.5 : 1	4,600	0.00005
4	13.70 to 20.62	48	17.87	19.37	18	1.5 : 1	4,500	0.00005
5	20.66 to 34.41	48	17.67	19.17	18	1.5 : 1	4,400	0.00005
6	34.45 to 54.40	48	17.47	18.96	18	1.5 : 1	4,300	0.00005
7A	54.44 to 69.00	48	17.25	18.75	18	1.5 : 1	4,200	0.00005
7B	69.00 to 69.25	48	17.25	19.25	24	1.5 : 1	4,200	0.00005
OFC	0.00 to 0.47	74	-	Various	-	1.5 : 1	4,200	0.0
7C	69.25 to 69.99	48	17.25	19.00	21	1.5 : 1	4,200	0.00005
8	70.04 to 85.08	48	15.75	15.75	-	1.5 : 1	3,500	0.00005
9	85.11 to 98.62	48	15.54	15.54	-	1.5: 1	3,400	0.00005
10	98.64 to 111.55	62	15.4	15.4	-	2.5 : 1	3,310	0.00005
11	111.55 to 114.05	84	15.4	15.4	-	2.5 : 1	3,310	0.00005
12	114.05 to 116.61	60	15.4	15.4	-	2.5 : 1	3,211	0.00005

The original design canal lining freeboard was 1.5 feet. But, when the canal was first put into operation, the lining was regularly overtopped during peak operations. The lining was then raised 1.5 feet in the mid-1960s to correct this problem. However, even with this additional freeboard, the canal lining continued to be overtopped when peak design flow conditions were attempted. High wind conditions that are prevalent in this area, would also exacerbate canal overtopping situations.

DEVELOPMENT OF HYDRAULIC MODEL

The U.S. Army Corps of Engineers River Analysis System standard-step backwater computer program (HEC-RAS Version 3.1) was used to compute channel hydraulics (U.S. Army Corps of Engineers, 2003). The program can simulate steady-state hydraulics, and includes processes that will evaluate losses through several types of structures, including radial gates.

The DMC was built in sections. Each section has one or more uniform trapezoidal cross section (Figure 2), with smooth transitions occurring at structures. In 2003, the top-of-lining was surveyed from MP 3.50 to just downstream of Check 13, resulting in approximately 1,000 observed water surface and top-of-lining elevations. An excel spreadsheet was developed combining the top-of-lining elevations with the template sections for each canal reach to automatically generate an HEC-RAS "geometry" file.

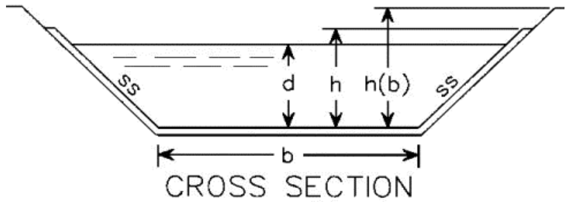

Figure 2. Schematic of Canal Cross Section

where “ss” is inverse side slope,
“d” is water depth,
“h” is depth to top of lining,
“h(b)” is depth to top of bank, and
“b” is bottom width

The DMC contains more than 100 structures. These were grouped into categories that could be modeled using the capabilities of HEC-RAS, as indicated in Table 2.

Table 2. Structures Modeled

Canal Feature	**Number Modeled**	**HEC-RAS Method**
Check structures	13	Radial gate
Inverted siphons	6	Buried culvert
Railway Culverts	3	Culvert
Bridge	65	Bridge
Overchutes	11	Bridge
Irrigation or gas pipe crossings	14	Bridge

The check structures (see Figure 3) are used to control upstream water levels, and were modeled as radial gates. Each check consists of three radial gates. All but two of the check structures also have side wing walls equipped with stop logs to assist with control of the upstream water surface elevation. At high flows, these gates may be raised above the water surface. In HEC-RAS, the model uses an orifice equation to calculate the head loss through the structure, when the tailwater depths exceed 80 percent of the headwater depth:

$$Q = C\ W\ B\ [2g(H-(Z_D-Z_{sp}))]^{1/2} \quad (1)$$

where “Q” is the flow; “C” is the coefficient of discharge (generally in the range 0.7-0.9); “W” is the combined width of the gate openings; “B” is the average height of the gate openings; “g” is the acceleration due to gravity; “H” is the depth of water upstream; Z_D is the downstream water surface elevations; and Z_{sp} is the invert elevation of the canal. Many of the checks also have concrete wing walls to contract the flow to the radial gates. These also serve as overflows to pass operationally mismatched flows.

Inverted siphons (Figure 4), designed to move the canal flow under larger waterways such as creeks, were modeled as culverts. Siphon inlet and outlet loss coefficients were applied to account for the transition structures located at the inlet and outlet to each inverted siphon.

Bridges (Figure 5), overchutes (Figure 6), and irrigation and gas pipe crossings where modeled in HEC-RAS as “bridges”. Information included pier locations and diameters, and low chord (bottom of structure) elevations. None of these structures are overtopped during the model simulations. However, some of the bridges and overchutes experienced pressure flow conditions, since the canal water surface did rise onto these structures.

Figure 3. Check Structure

Figure 4. Inverted Siphon Entrance

Figure 5. County Bridge

Figure 6. Overchute

MODEL CALIBRATION

During the 2003 canal survey, the DMC was operated to provide near-capacity flows of around 4,300 cfs for much of the time. Water surface elevations were measured at over 600 locations along the canal (Figure 7). Generally, the radial gates at Checks 1 through 12 were out of the water, and the operations of the O'Neill Pump/Generating Plant and the gate openings at Check 13 were used to maintain the canal levels. Flows were measured upstream at the Jones Pumping Plant (JPP) and downstream at the O'Neill Pump/Generating Plant, and estimated at the various check structures. In addition, "metered" flows were provided at the various withdrawal points along the canal. Figure 8 shows that the flows are progressively smaller in the downstream direction. The figure also shows the fluctuations of these daily-averaged flows.

The DMC is very flat, with a designed longitudinal slope of 0.00005, or three inches per mile. Initial model runs showed that an increase in flow of only 50 cfs results in an increase in water surface elevation on the order of 0.15 feet (2 inches) in the upper parts of the canal. In addition, JPP flows were measured as daily volumes, and therefore did not include any shorter-term fluctuations. This raises several model calibration concerns. Even though the DMC was generally operated with consistently large flows, there were daily variations in flow on the order of 50 cfs or more. In several reaches, the surveyed water surface elevations did not form a smoothly sloping water surface, and while the variations were small (on the order of +/- 0.1-0.2 feet), they were significantly larger than the vertical accuracy in the survey. This may be caused by a number of factors, including wave action due to high winds, tidal influence at the intake to the JPP, and system demand (i.e., turnout usage (on/off) during any given day). We used this water surface variability of +/- 0.1-0.2 feet as a guide to judge the accuracy of the model calibration.

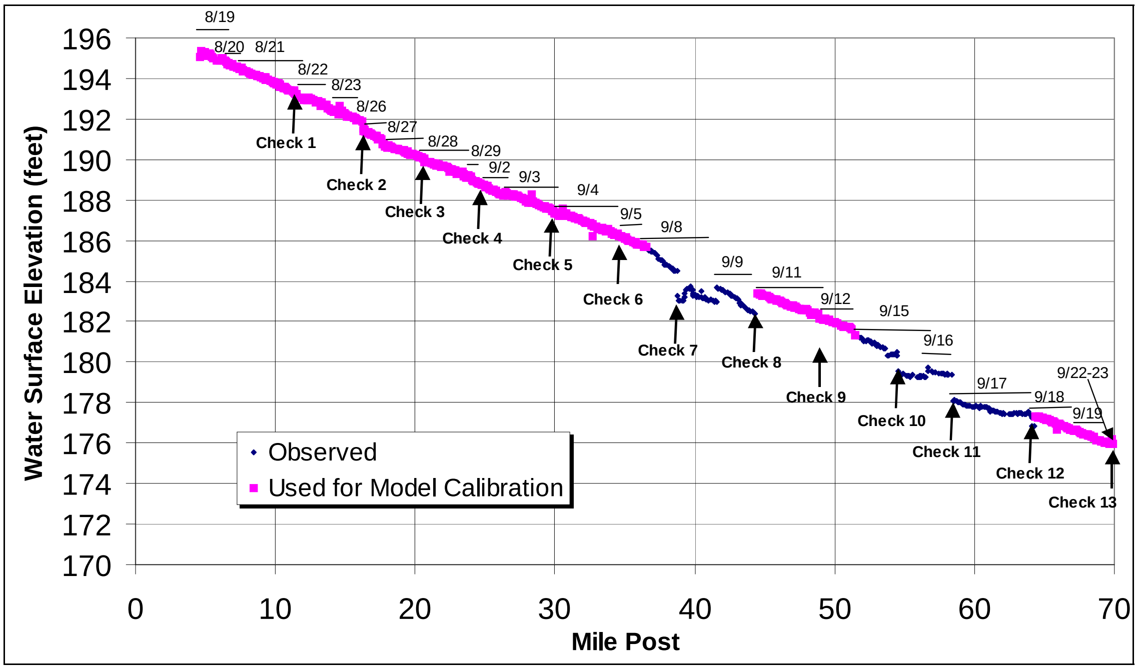

Figure 7. Surveyed Water Surface Elevations

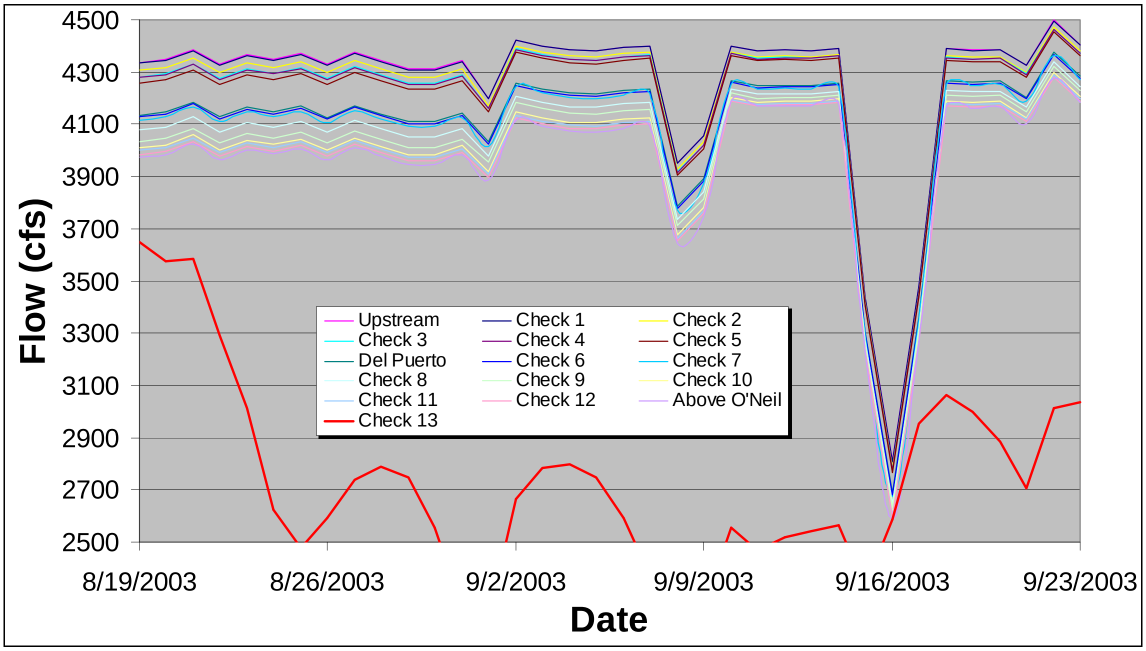

Figure 8. Flow Profiles along Canal

We therefore decided to approach the model calibration in two ways, using only water surface measurements during periods of generally steady flow (shown in magenta in Figure 7). First, we simulated average flows in reaches of the canal where flow conditions were stable for a period of 1 to 3 days and "fixed" the stage at the downstream end of each canal reach to an observed water surface elevation. This approach was used to stabilize the model, and to identify the general range of model hydraulic parameters, including Manning's *n* friction values, and expansion/contraction coefficients at the various structures. Second, we modeled 12 flow periods (generally corresponding to 1-to-3 survey days), and compared computed water surface elevation from the model with observed water surface elevations measured on the same day or days for an individual flow profile. Hydraulic parameters were modified until a best fit condition was reached. This approach was used to determine if an accurate water surface profile could be projected all the way upstream without resorting to "fixing" values along the canal. The calibration produced the best fit hydraulic parameters shown in Table 3. Figure 9 shows the agreement in the upstream half of the DMC, and sensitivity to Mannings *n* roughness values.

Table 3. Hydraulic Model Calibration Parameters

Hydraulic Parameter	Parameter Value
Mannings *n* of canal	0.016
Mannings *n* of inverted siphons	0.014
Contraction/expansion coefficients in canal	0.0 / 0.0
Contraction/expansion coefficients at Checks	0.1 / 0.2
Contraction/expansion coefficients at siphons	0.1 / 0.2
Contraction/expansion coefficients at "bridges"	0.1 / 0.2
Loss at "bridges"	Used "Energy Equation"

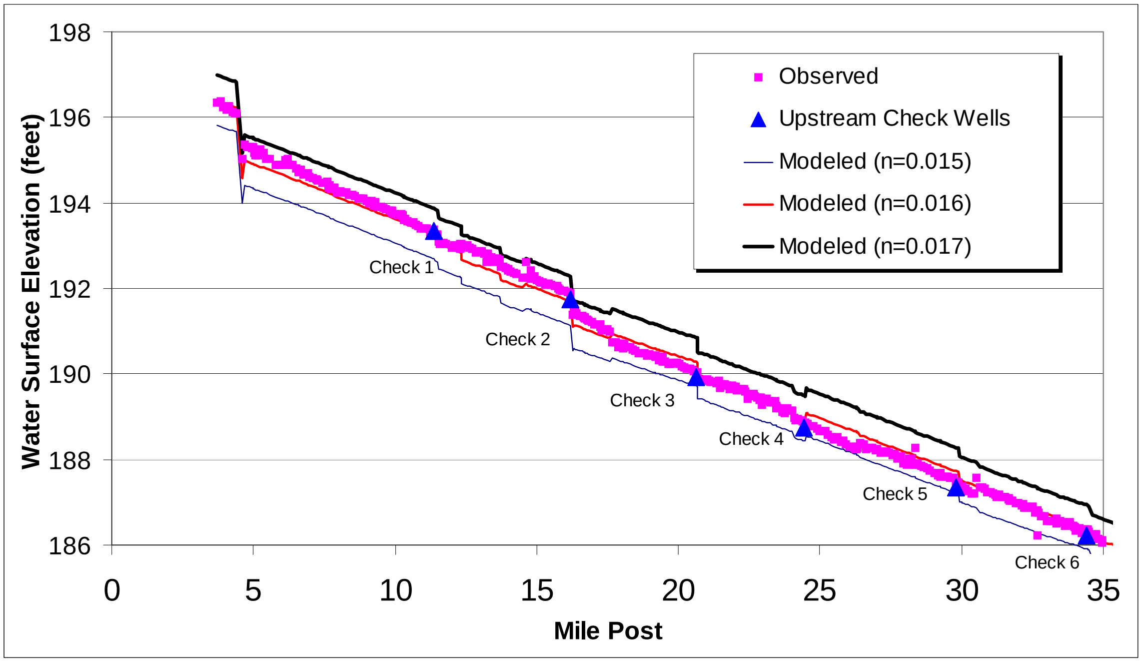

Figure 9. Simulations of Multiple Profiles in Lower Canal

EFFECT OF TIDES ON CANAL FLOW

It is known that tides in the Delta influence the pumping rates produced by the Jones Pump Plant (JPP). However, flow data at the JPP are not available through direct measurements. Rather flow determinations are based upon various indirect methods that are correlated to plant discharge flow. These methods include watt-hour meter readings for each pump unit, total water surface level differential between upstream and downstream of the plant, and current meter measurements taken from a bridge over the DMC located at Mile Post 4. Use of these methods allows JPP flows to be determined on an average daily basis. As such it is not possible to compare flows to tidal elevations that fluctuate throughout the day. In September 2004, water surface elevations in the upper canal were observed to be near or above the top of the lining during a period of spring high tides and near-capacity flows in the canal. A siphon breaker system is located at the end of the Jones Pump Plant discharge pipes just before they connect to the DMC. This siphon breaker system is used to regulate minor flows delivered to the canal (50 to 300 cfs), quickly lowering canal water surface elevations when required.

To examine this effect further, a survey was conducted during another spring high tide in October 2004. During this event, pump flows were manually recorded each hour. Near-capacity flows were pumped into the canal and the downstream canal water surface elevations were observed (for lining overtopping). A current meter was used to directly measure flow in the canal at MP 4.98, and data from the tide gauge in front of JPP were obtained.

A part of the analysis is shown in Figure 10, and shows the correlation between the tide water surface variations to pumping rates at the JPP. The figure also shows the effect of opening the siphon breakers, resulting in a reduction of perhaps about 100 to 200 cfs (or about a two-to four- inch reduction in the water surface elevation in the upper canal) per breaker.

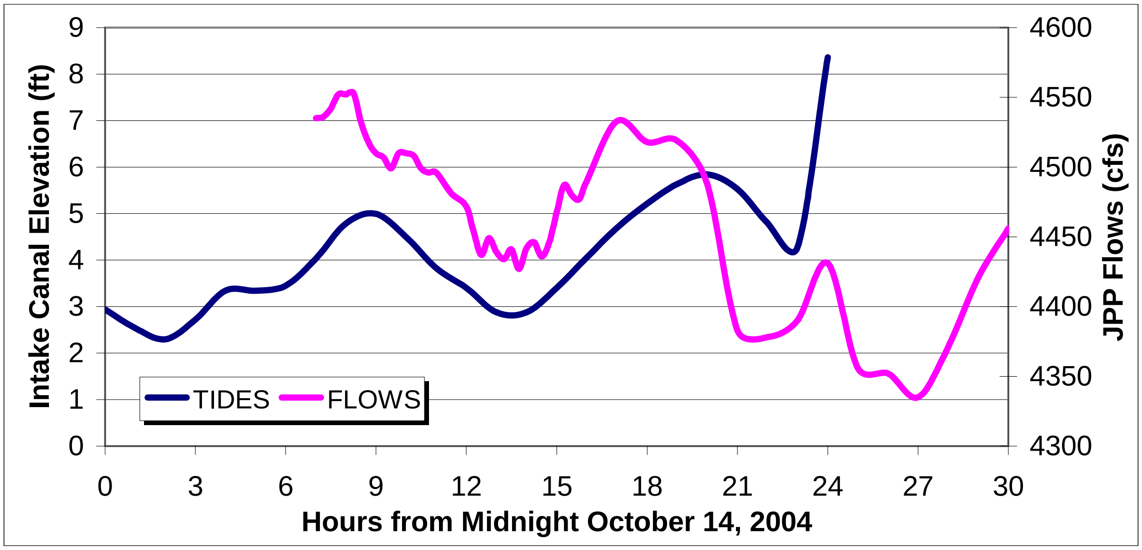

Figure 10. Observations from October 2004 Flow Test

DATUM PROBLEM

Because HEC-RAS was being run in steady-state mode, the model required downstream boundary conditions (1) just downstream of Check 13 on the main canal and (2) at the downstream end of the O'Neill Forebay Canal (OFC). As water is pumped from the OFC up to the San Luis Reservoir, we used flow and stage data measured near the dam to develop a rating curve, and specified the downstream stage boundary in the OFC as a function of the flow diverted from the DMC into the OFC. Initial simulations indicated an inconsistency in modeled stages at the confluence of the DMC and the OFC. The "discrepancy" was more than two feet (Figure 11).

Considerable time was spent exploring the reason for the inconsistent water surface elevations at the confluence. In particular, we noted that the model results at the confluence, reflecting the much larger flow (4200 cfs of the total flow of 4600 cfs) being diverted into the OFC, resulted in a backwatered pool in the DMC upstream of the confluence. A crude model was developed to evaluate the possible influence of a sediment bar that had historically formed on the inside of the bend from the DMC to the OFC (Figure 12). However, because this system is so flat (slope of 0.00005) and deep (about 17 feet), inclusion of the sediment bar had virtually no effect.

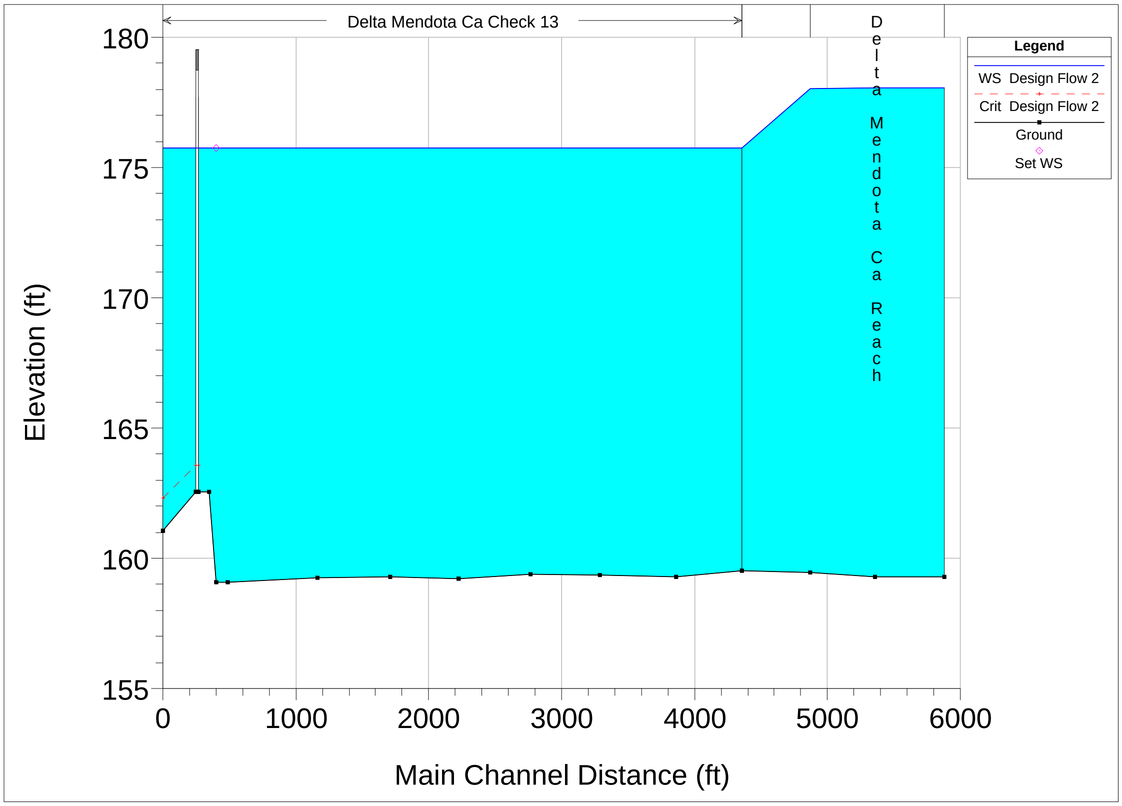

Figure 11. Initial Stages at the Confluence of the DMC and the OFC

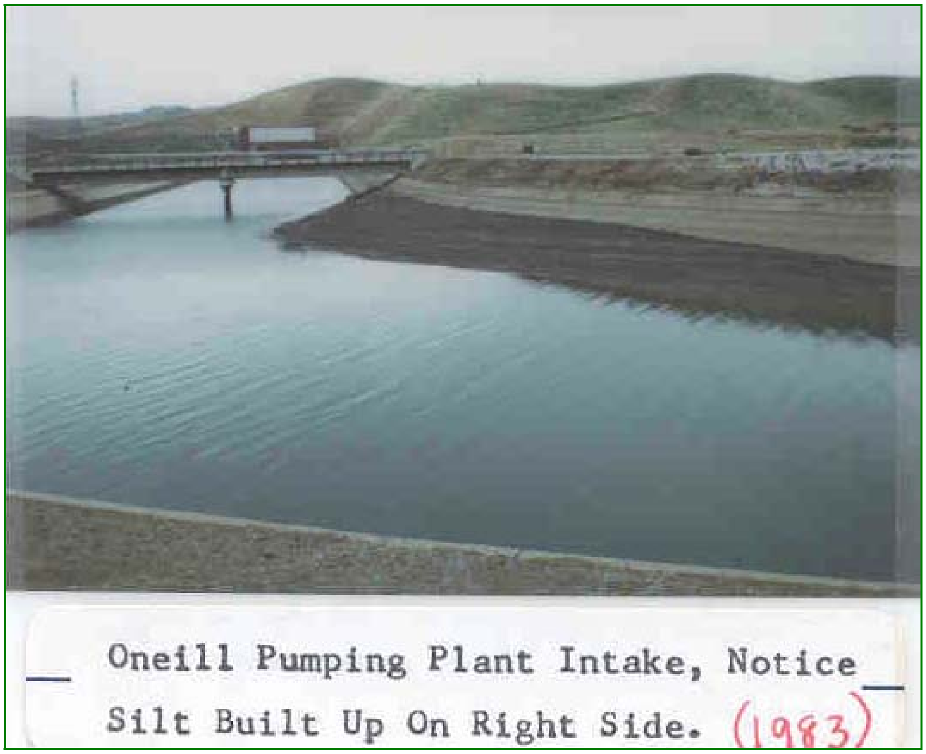

Figure 12. Observed Sediment Bar at Confluence of the DMC and the OFC

Finally, parts of the system from the confluence to the San Luis Dam were re-surveyed. This revealed that the observed stage near the dam was referenced to a different datum (the San Luis Datum) than the survey measurements developed for the DMC and the OFC (all based upon the NAVD88 Datum). The difference was almost exactly the difference seen in the model results. Once the downstream rating curve at the San Luis Dam was re-adjusted to NAVD88, the model results were consistent at the confluence within 0.1 feet.

GATE COEFFICIENTS

The main purpose of the study was to evaluate the capacity of the DMC, and we were able to both calibrate and run the hydraulic model with all checks control gates fully open. With the gates out of the water, we did not have to calibrate gate structure coefficients. Later however, consideration was given to developing an unsteady-flow model of the canal system for operational analyses. This required the ability to model the system over a range of flows, and therefore gate operations. We decided to initially estimate the gate coefficients using the steady-state hydraulic model, and selected three flows (each generally constant for several days) that resulted in most of the gates being lowered into the water.

In HEC-RAS, radial gates, such as those in the DMC, are modeled using a range of techniques that depend on the hydraulic conditions at each check structure. Because the most-downstream structure, Check 13, was operated to maintain a near-constant level in Pool 13 and as most of the upstream flow was diverted into the OFC during these periods, the downstream boundary of the hydraulic model was fixed at the water surface elevations measured just upstream of Check 13. As the DMC is very flat (slope is 0.00005) and deep (about 17 feet), and the head differences across each check structure are usually small (order of one foot, except at Check 1 where it might be about two feet), the hydraulic model defaults to an “orifice equation” solution for these conditions.

In HEC-RAS, the recommended default orifice coefficient is C=0.8, and this was used as a starting point. The values at individual Checks were then adjusted to best fit the observed heads and head differences over the three flows modeled. Table 4 summarizes the results over the three simulation periods.

The biggest differences occurred at Checks 8 and 11. Generally, each check is operated with each of the three gates opened the same amount. However, at Check 11, one gate was almost wide open, one gate was closed, and the remaining gate was generally being used to regulate the upstream stage. In addition, the model usually over-predicted the stage downstream of Check 11 but was very close just upstream. This is due in part to the backwater effect from Check 12, which was accurately simulated, and which therefore controls the stage downstream of Check 11. The opposite problem was seen at Check 8 were the “good” results at Check 9 resulted in the model under-predicting the stage downstream of Check 8. Overall, however, the results are quite close, and the resulting orifice coefficients are reasonable.

Table 4. Orifice Coefficients for Simulation of May 2004

Check	Orifice Coeff.	Gate Opening #1	Gate Opening #2	Gate Opening #3	Computed DIFF	Observed DIFF	Difference of DIFFs
CK12	0.77	7.13	7.13	7.13	0.91	0.83	0.08
CK11	0.75	16.2	0	4.28	0.45	0.83	-0.38
CK10	0.75	8.07	8.07	8.07	0.75	0.79	-0.04
CK9	0.77	7.59	7.59	7.59	0.81	0.71	0.1
CK8	0.8	8.08	8.08	8.08	0.67	0.17	0.5
CK7	0.8	7.13	7.13	7.13	0.93	0.56	0.37
CK6	0.75	9.95	9.95	9.95	0.6	0.46	0.14
CK5	0.8	7.13	7.13	7.13	0.97	0.74	0.23
CK4	0.75	8.08	8.08	8.08	0.82	0.68	0.14
CK3	0.77	8.55	8.55	8.55	0.73	0.54	0.19
CK2	0.8	17	17	17	0.22	0.13	0.09
CK1	0.75	5.22	5.22	5.22	2.02	2.07	-0.05

Finally, Figure 13 compares the observed head differences across the check structures for the three simulation periods with the theoretical values calculated using an orifice coefficient of 0.8 and the measured gate openings. The solid line is a "best fit" through the observations using a power function to demonstrate the observed spread in the observations. The figure shows the use of an orifice equation to simulate the "drowned" conditions at the check structures with the "default" coefficient of 0.8 gives reasonable results within the spread of the observed head differences. At Check 1, however, with the largest measured head differences (up to two feet), the model defaults to the "orifice" equation for large gate openings (generally half open or more), but to the "radial gate" equations for smaller openings that give great head differences across the structure.

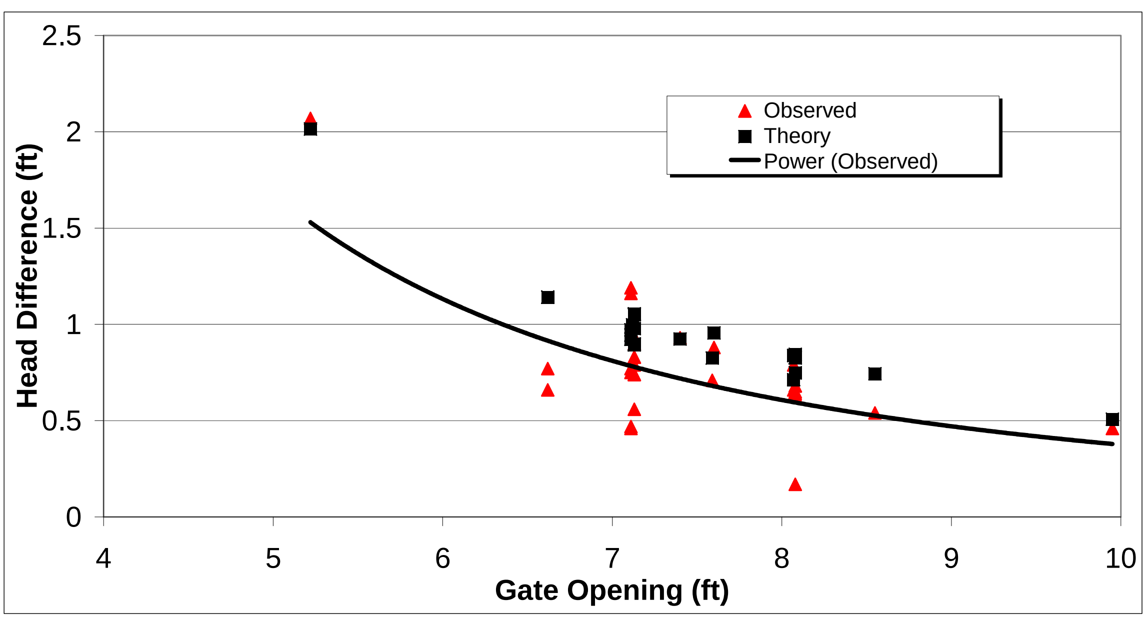

Figure 13. Comparison of Observed and Theoretical Head Differences for an Orifice Coefficient of C=0.8

APPLICATION

Three initial project alternatives were simulated in the study reach:

1. To evaluate the ability of the canal to convey its original design capacity ("Design Flow 1"). The original design is for the canal to pass 4,600 cfs upstream, decreasing to 4,200 cfs at the San Luis Wasteway located just upstream of Check 13, with 3,500 cfs passing Check 13. In addition, the means and techniques for the canal to convey these flows were also evaluated.
2. To evaluate the ability of the canal to convey 4,600 cfs to the O'Neil Forebay Canal, with 4,200 cfs routed to O'Neil, and 400 cfs passing Check 13 ("Design Flow 2"). Again, means and techniques for the canal to convey these flows were also evaluated.
3. To increase the design capacity upstream to 5,100 cfs, and remove additional 600 cfs at MP 7.2 to a proposed Intertie pumping plant to the California Aqueduct.

The purpose of the first two sets of simulations was to determine how much flow the existing canal could convey and how this would affect the canal lining freeboard. Additionally, the effect on canal capacity of raising impacted structures out of the canal water surface was evaluated. The purpose of the third alternative was to determine if the upper canal could convey slightly more flow to the Intertie location, remove a portion of that flow through the Intertie, and what the impact on the canal lining freeboard might be. Figure 14 shows the results of the first two alternatives, including the effect of raising structures impacted by high water levels.

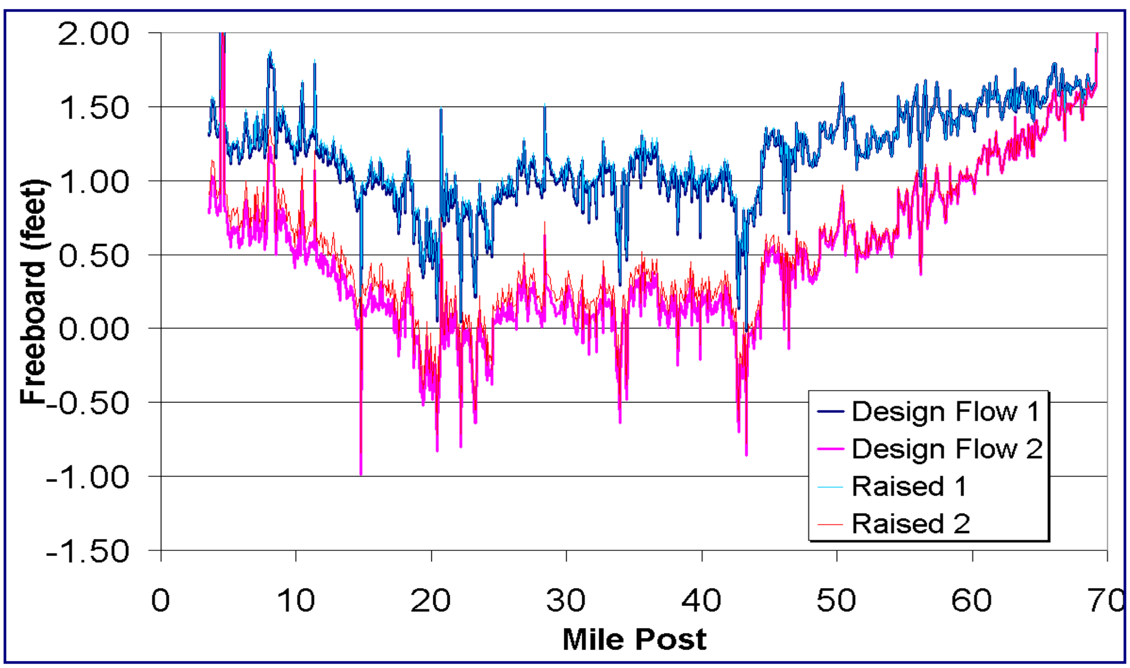

Figure 14. Simulations of Design Flows in Canal

The results (Figure 14) show the locations where the freeboard would be stressed, and perhaps vulnerable to wave actions, and locations where the existing lining would be overtopped. The results also showed that raising structures, while perhaps necessary for structural (buoyancy) reasons, provided very little additional hydraulic conveyance capacity because of the very small slope of the canal. The model results are being used to evaluate improved operating methods for the canal, canal lining freeboard requirements, and which structures may need to be raised above high water levels.

DISCUSSION

We report the development and calibration of a hydraulic model of the Delta-Mendota Canal (DMC) between Checks 1 and 13 (about 66.5 miles of canal). The model was developed using HEC-RAS with uniform design cross sections for all reaches of the canal. Various types of hydraulic structures were added, including check structures (radial gates), bridges, inverted siphons, overchutes, etc. The model was calibrated to about 600 water surface elevations measured along the canal.

In this paper, we have focused on the use of a hydraulic model to better understand system processes. This included (1) the aging of the canal's lining, (2) its decreasing capacity, (3) the influence of tides on inflows at the Jones Pump Plant, (4) a discrepancy is datums, and (5) the selection of gate coefficients.

The DMC was originally designed and built between 1946 and 1952, based on a Kutter's *n* of 0.014. This equates to a Manning's *n* of 0.0138. USBR studies later produced a chart, presented in Design Standard No. 3 (USBR, 1967), showing Mannings *n* as a function of hydraulic radius. In the study area, the design hydraulic radius of the DMC varies between 11.2 and 10.77. Using Design Standard No. 3, this would yield a Manning's *n* of 0.0153. This suggests two things; (1) the canal was probably undersized according to Design Standard No. 3 (*n*=0.0138 versus 0.0153), and (2) aging has probably contributed to the even higher calibrated value (*n*=0.0153 versus 0.016). This increases water surface elevations during peak flow periods or reduces the maximum flow the canal can carry if freeboard requirements are imposed.

Several simulations were performed to investigate the capacity of the current canal, and assess possible measures to increase its capacity. These simulations demonstrated that, again due to the very flat canal slope, raising structures above the water surface would do little to improve the capacity. Rather, other measures, such as raising the canal lining or removing capacity from the upper end of the canal, would produce more effective results.

We observed that tidal variations at the JPP Intake can increase flows in the DMC by 100-200 cfs, depending on the tidal period. This can cause additional increases in water surface elevations in the canal, and further threaten overtopping of the canal lining. Downstream, Check 13 is generally operated to maintain a constant water surface elevation of about 176 feet. However, at design flows, the increased roughness would produce higher upstream canal water surface elevations, even with all check structure radial gates set wide open.

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ORLAND UNIT WATER USERS ASSOCIATION REGULATING RESERVOIR, AN EXAMPLE OF VERIFICATION-BASED MODERNIZATION PLANNING

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Rick Massa[2]

ABSTRACT

The Orland Unit Water Users Association (OUWUA or Association) desires to modernize its delivery system to increase delivery flexibility and conveyance efficiency. The Association recognizes the need to improve the level of service and increase water supply reliability to reduce the incidence of growers converting to groundwater. Regulating reservoirs are an important part of the Association's modernization plans, and once constructed, will provide the benefit of reducing system losses. Combined with the Association's current conjunctive water management plans, regulating reservoirs may enhance water supplies available for regional initiatives.

This paper describes the results of a Feasibility Investigation conducted to develop firm estimates of the benefits of the regulating reservoir, near-final designs, specifications and costs. Verification-based modernization planning, a technique that fuses traditional facilities planning with water conservation verification procedures, was applied to develop estimates of the expected benefits in the context of a water balance with and without the project.

INTRODUCTION

The Orland Unit Water Users Association (OUWUA or Association) recognizes the need for system modernization to improve water use efficiency and is aggressively following a conceptual modernization plan. OUWUA is utilizing a strategy of re-routing flow fluctuations along main canals to points where these flows can be re-regulated. These re-regulating points are either regulating reservoirs or discharge points to the Tehama-Colusa Canal (TCC) where OUWUA receives credit to offset its Stony Creek diversions[3]. The conceptual modernization plan focuses on facilitating the routing of these flow fluctuations by improvement of main canal structures and regulating reservoirs, and installation of SCADA technology.

Primary goals identified by the OUWUA include replacing obsolete structures, increasing water delivery flexibility, and increasing conveyance efficiency. Among other benefits,

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[3] Upon completion of Black Butte Reservoir in 1964, the United States and the Orland Unit Water Users' Association entered into a contract providing for the exchange of water. In present Black Butte water accounting, OUWUA discharges into the TC Canal are credited against (CVP) supplies diverted from Black Butte Reservoir.

the improved levels of service made possible through modernization will ensure continued use of renewable surface water supplies, reducing the incidence of farmers converting to readily available groundwater supplies. This, in turn, will protect local groundwater supplies for use in dry periods, when needed.

Regulating reservoirs are an important part of OUWUA's modernization plans, in that they minimize system spillage while enabling system operators to provide additional delivery flexibility to growers. By providing improved surface water service, these reservoirs help the Association accomplish its conjunctive water management goals, through which local and regional water supply reliability may be improved.

Proposition 50, the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002 passed by California voters provides funds to assist agencies improve water use efficiency. This grant program implements California Water Code Chapter 7, Section 79550 (g) of Proposition 50 and provides the funds for this application of verification-based modernization planning.

Verification-based modernization planning is "a tool to improve the irrigation system modernization planning process and to effectively monitor the post-project effects on system performance" (Burns, J.I., et al., 2000). The aforementioned Proposition 50 grant program requires monitoring of post-project system performance with annual reports for five years following project completion. Thus, the verification-based modernization planning was used to provide a foundation and framework for future monitoring of post-project performance.

PHYSICAL AND INSTITUTIONAL SETTING

The Orland Project (or Project), constructed between 1907 and 1918 and operated and maintained by the Orland Unit Water Users Association (OUWUA or Association), irrigates about 20,000 acres in northern Glenn County (Figure 1). The Project diverts roughly 100,000 acre-feet (AF) of water from Stony Creek in most years, shortages occur only in the driest years. One hundred and forty miles of mostly concrete lined canals distribute water into six "beats" (ditch tender service areas) (Figure 2). Beats One, Two, Three and Four are served by the Southside system via direct Stony Creek diversions at Black Butte Dam into the South Canal. The Southside system serves roughly two-thirds of the Project area. Beats Five and Six are served by the Northside system via direct diversions from Stony Creek into the North Canal at the North Diversion, a diversion dam located approximately four miles downstream of Black Butte Dam.

Beats One, Two and Three are independent units receiving water at diversion points on the South Canal. The South Canal terminates at the head of Beat Four and becomes Lateral 40 with all remaining water designated for Beat Four deliveries. Beats Five and Six serve roughly one-third of the Project on the north side of Stony Creek. Beat Five receives water from the North Canal via sub-lateral turnouts with the remaining water passing through to Beat Six. Beat Two covers the largest area and serves the most water users (Table 1)

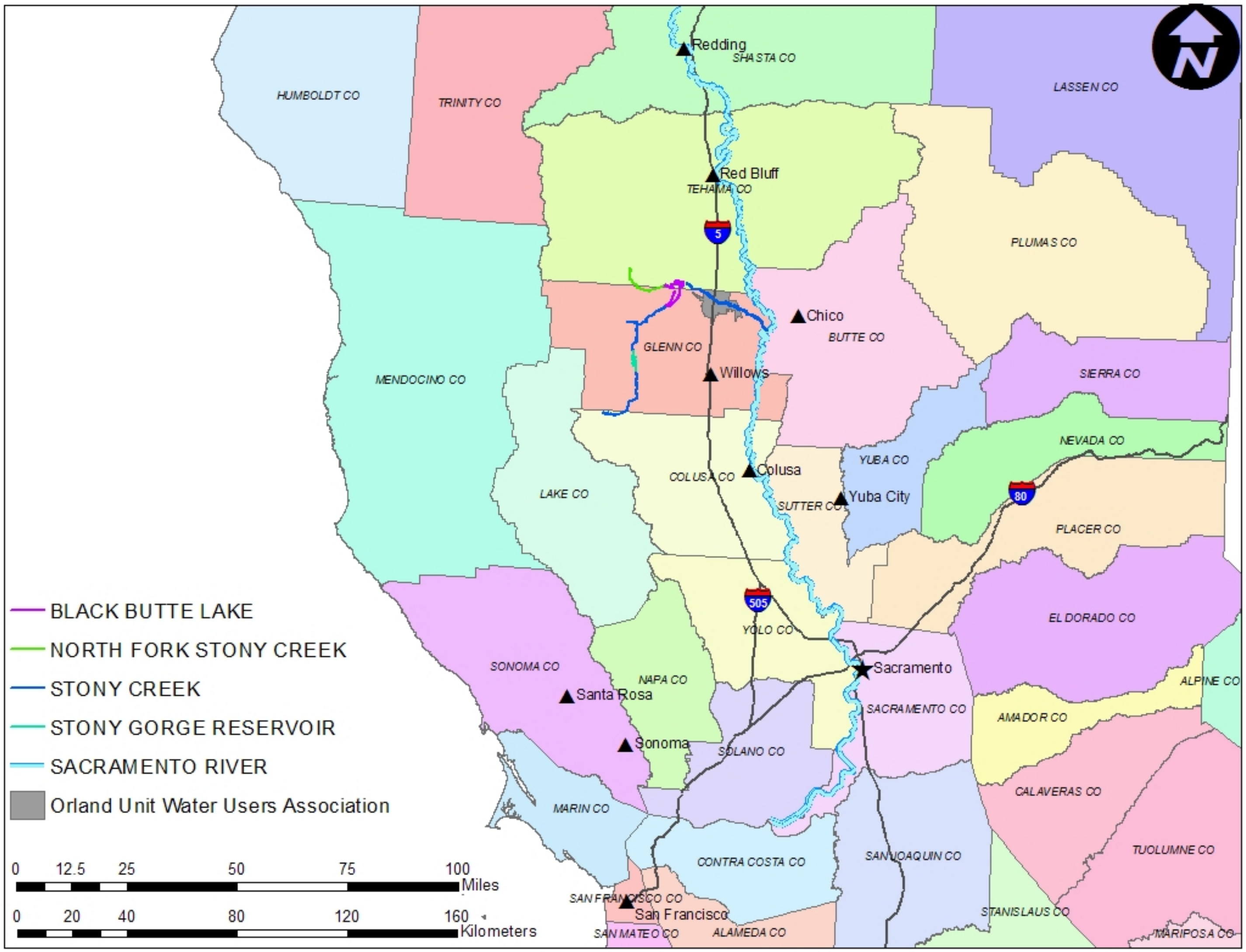

Figure 1. Location of the Orland Project in Northern California

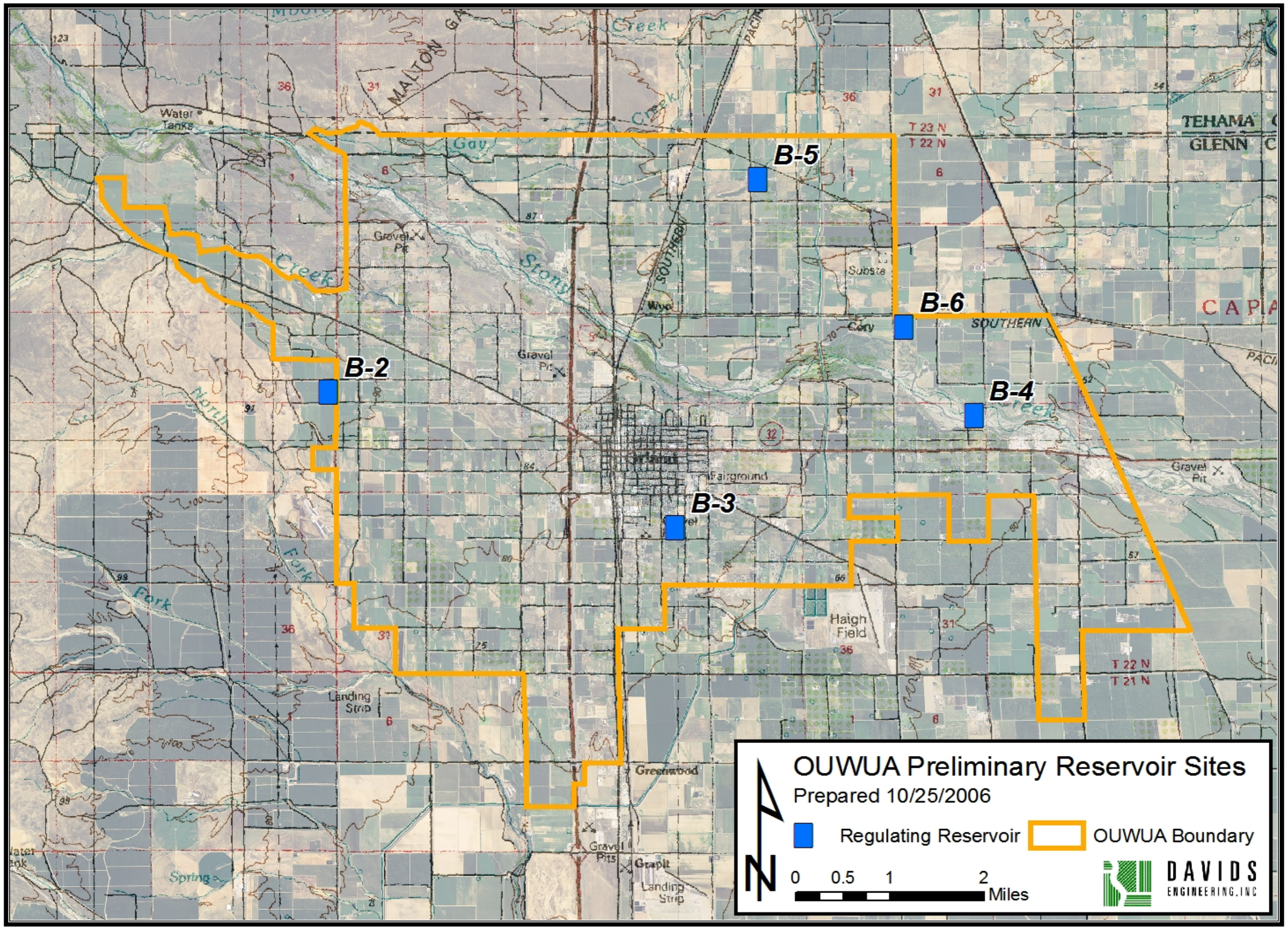

Figure 2. OUWUA Boundaries, Beats and Preliminary Reservoir Sites

Table 1. Irrigated Area, Water Users, Canal Branches and Lengths for OUWUA Beats

Beat No.	Irrigated Area, acres	Number of Water Users	Number of Canal Branches	Total Canal Length, miles	Average irrigated field size, acres
Beat 1	1,323	70	6	17.6	19
Beat 2	4,492	179	11	24.6	25
Beat 3	2,091	200	19	21.6	11
Beat 4	2,586	128	16	27.3	20
Beat 5	2,031	80	9	15.7	25
Beat 6	3,455	125	9	19.7	28

Irrigation water is distributed in open, upstream controlled canals and ditches on a rotation pattern—specifically, a “head” of water is passed from one grower to the next on a 24/7 basis throughout the irrigation season. Rotational irrigation deliveries generally result in over-irrigation in the spring and fall and under-irrigation in the summer. Consequently, yields are less than optimum, causing an increasing number of growers to convert from surface irrigation with Project water to drip irrigation systems supplied by private groundwater wells.

Because parcel sizes are generally small (averaging 20 acres) and canal flows are large (six to 12 cfs), water is typically passed from one grower to the next every few hours. These frequent flow changes cannot be made with perfect timing and accuracy, resulting in high canal spillage due to the lack of regulating storage in the distribution system.

The Army Corps of Engineers (USACOE), the operating entity of Black Butte Dam, receives water orders from OUWUA for the North and South Canal and regulates the flows downstream from the Black Butte Reservoir accordingly. OUWUA is currently restricted to two orders per day-- at 7 am and 1 pm during the irrigation season. Due to the inability to reduce Black Butte heading flows in the late afternoon or evening, water is sometimes spilled throughout the night when an irrigation “run” is finished, or when an irrigator is unable to take the water.

This paper describes the selection of the proposed regulating reservoir site, the proposed reservoir operational procedures, the water savings estimate developed using the verification modernization planning method and the regulating reservoir and lateral improvements design.

RESERVOIR SITE SELECTION-CRITERIA AND SELECTION

Five potential regulating reservoir sites were identified. Available information and data related to these five sites were collected and reviewed. All five potential sites were inspected and discussed at length with OUWUA staff. Sites were evaluated with respect to the following criteria: (1) site size and suitability for a reservoir, (2) access and ease of construction, (3) suitability of site soils and materials for construction, (4) availability of grid power, (5) potential for water savings, (6) existing land use/zoning and cost, (7) landowner’s willingness to cooperate and (8) potential for environmental impact.

The five potential sites were scored from 1 (worst) to 5 (best) for each criteria based on discussions with OUWUA staff, site inspections and additional information collected. The potential reservoir site located in the area identified by OUWUA as Beat Two emerged with the highest score after the sites were ranked with equal weight on the seven criteria. The existing land use for all sites was agriculture and no obvious environmental problems were noted. The environmental review of the highest scoring site, located within Beat Two, was supported by a biological and cultural resources evaluation. No special status plant or wildlife species were observed in the area proposed for the Beat Two reservoir. The cultural resources review found that no previously recorded cultural resources were located in the area proposed for the Beat Two reservoir.

OPERATIONS PROCEDURES AND BENEFIT ZONES

Two "head" sizes (delivery flow rates) of 11.5 and 6 cfs are distributed to users in a rotational delivery system. Rotation intervals vary from 12 days in the middle of the irrigation season to14 days early and late in the irrigation season. Delivery durations, based on the head size and irrigated acreage, vary from less than 0.5 to more than 24 hours. On average, water is moved from user to user 15 times each day with the movement of water handled by the users themselves about 95 percent of the time. Nighttime operations are usually limited to handing water from one user to the next by the water users themselves. Should a head need to be moved from one lateral to another at night, the last user is often asked to keep the head until daylight. Analysis of historical spillage records identified the following three main causes of spillage:

1. moving heads between growers (head movement spillage),
2. level fluctuations at the heads of laterals (heading fluctuation spillage) and
3. inability to respond in a timely manner to changes in demand (responsiveness spillage)

Based on this detailed review, procedures for system operation with the proposed regulating reservoir in place were formulated with the objectives of reducing system spillage and increasing delivery flexibility. Existing operations procedures and those recommended under future conditions with the regulating reservoir are summarized in Table 2.

Six benefit areas were defined to quantify reservoir benefits (Figure 3). In each benefit area each of the three spillage causes are addressed to differing extents. In benefit area one, all spillage, regardless of the cause, would be intercepted by the proposed reservoir and significant additional flexibility would be available to growers with turnouts without increasing delivery system spillage. Proposed automation will minimize the spillage due to all causes from benefit area two, but, due the location of this benefit area downstream of the reservoir, some spillage is unavoidable. In benefit areas three and four, head movement spillage cannot be captured, and flow settings at a lateral heading must be changed to convey responsiveness spillage to the reservoir. Benefit areas five and six are operationally the most distant from the reservoir, making it more difficult to convey responsiveness spillage from these areas to the reservoir.

Table 2. Summary of Operations Procedures under Existing Conditions and Future Conditions with the Proposed Regulating Reservoir

Operations Procedures	Existing Conditions	Future "With-reservoir" Conditions
Water Ordering and Delivery		
Delivery Date and Time	Date and time fixed by rotation with very limited flexibility under extraordinary circumstances.	Date and time fixed by rotation with increased flexibility under defined criteria.
Delivery Flow Rate	Two basic flow rates--6 and 11.5 cfs, small numbers of other flow rates in special circumstances	Two basic flow rates--6 and 11.5 cfs, increased numbers of other flow rates in wider circumstances
Duration	84% of durations 10 hours or less	Expect longer durations as lower flow rates become more common.
Moving water between growers	Growers inform next grower when to start receiving delivery.	Same as existing with potential for limited arranged demand.
Night operations	Significant on-farm spillage when heads end at night and must be moved to a grower on another lateral.	On-farm spillage reduced significantly in primary benefit zone where ditch tender can remotely reduce flow at lateral heading and have the flow passed to the proposed reservoir. Reduced to a lesser extent in secondary and tertiary benefit zones due to greater distance and less direct operational connection to proposed reservoir.
Spillage Causes		
Head Movement Spillage		Reduced on Lateral 210
Heading Fluctuation Spillage		Reduced on laterals taking water from Lateral 210
Responsiveness Spillage		Eliminated in primary benefit zone and reduced to greater and lesser extents in secondary and tertiary benefit zones, respectively.
Ditch Tender Ordering Procedures	Total heads required to meet demand as daily order from South Canal	Total heads required to meet demand, determine planned reservoir outlet flow and subtract from total heads to equal order from South Canal
Lateral Operations	Fully manual operations	Mix of manual and automatic operations
Checks	Manually set checks with boards	Lateral 210 automatic level control checks
Headings	Manually set heading openings	Selected headings remotely controlled

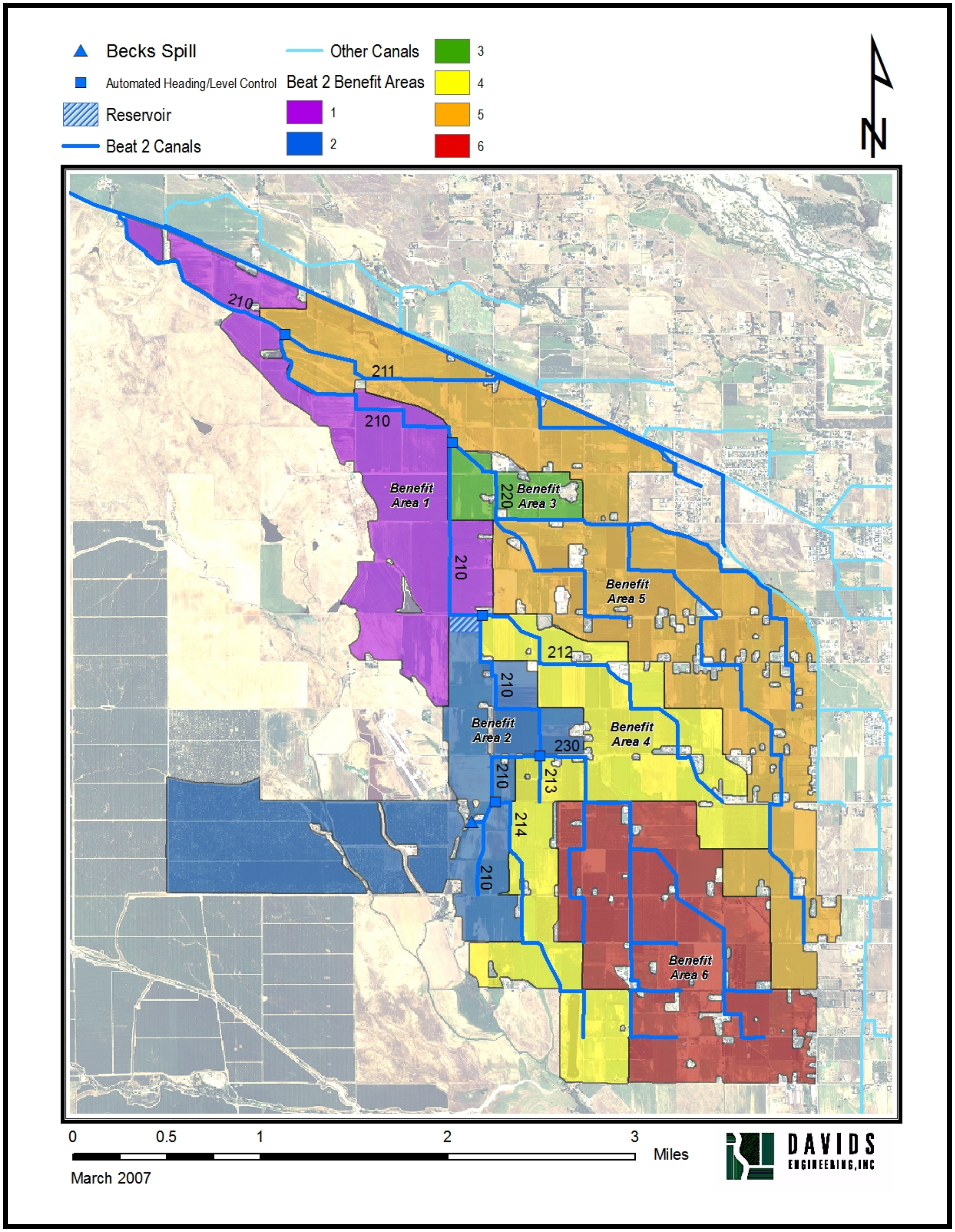

Figure 3. Operations Benefit Zones in Beat 2

WATER CONSERVATION ESTIMATE

The verification-based modernization planning process estimates water savings by preparing a water balance for the area within which canal operations and delivery flexibility would be enhanced by the reservoir. This area, or "benefit zone" was defined earlier as all of Beat 2. The water balance diagram for Beat 2 is presented in Figure 4. The water balance was prepared for the 2006 irrigation season, which ran from early May through late October, and computes flows on a monthly time step. The water balance results are tabulated in Tables 3 and 4.

Based on the water balance, selected flow paths are targeted for conservation. These flow paths, in decreasing order of priority, are measured flows at Beck's Spill (location where spillage from Beat 2 is measured), unmeasured spillage to irrigated lands and tailwater from irrigated lands. With the project, water that would have either spilled through Beck's spill or to irrigated lands would be stored in the proposed regulating reservoir. In addition, growers would be able to reduce tailwater by shutting off delivery when irrigation is complete, with the remaining unused water being conveyed to, and stored in, the reservoir.

The total spillage volumes for the 2005 and 2006 irrigation seasons at Beck's Spill were 2,900 and 2,600 acre-feet, respectively. Verification-based planning requires estimating the changes to the targeted flow paths. The 2006 pre-project record was considered representative of future spillage magnitudes if the project is not constructed, and thus assumed to be the without-project spillage volume. With-project spillage volumes were estimated using a spreadsheet model to simulate reservoir operations on a 15-minute time-step, based on the operations procedures

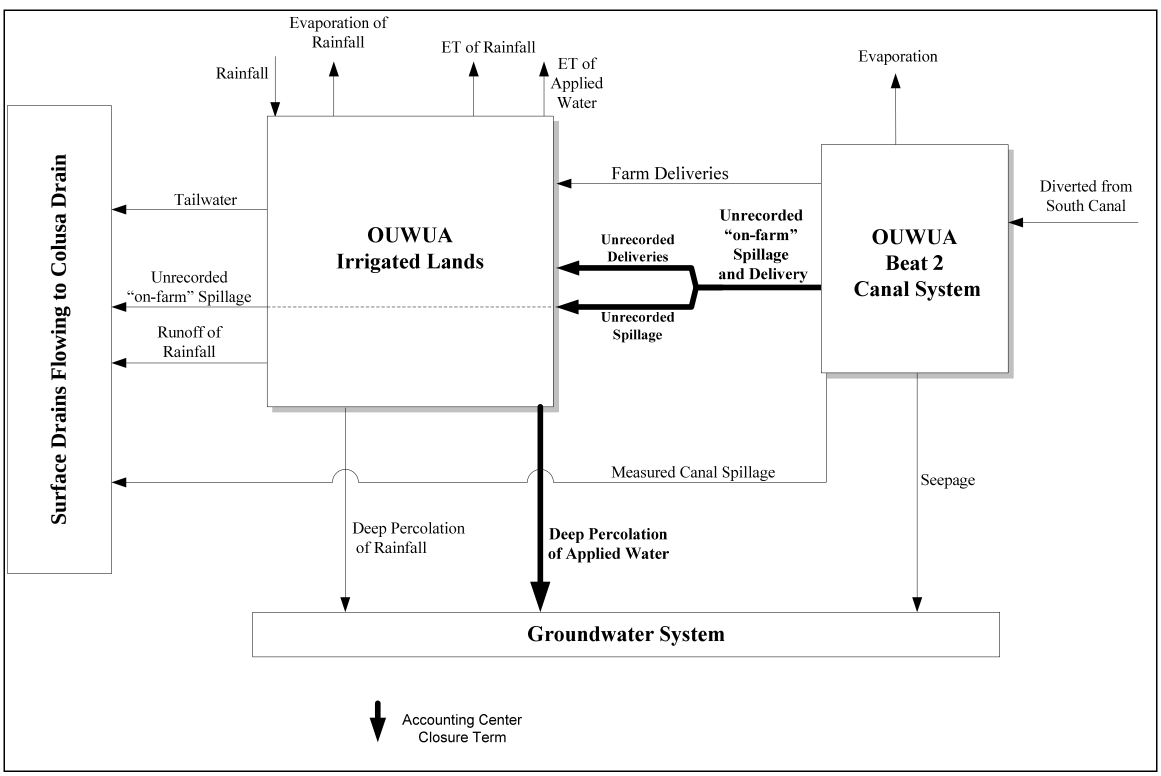

Figure 4. OUWUA Beat 2 Water Balance Schematic

Table 3. Summary of 2006 OUWUA Beat 2 Canal Water Balance

		Inflow	Outflows						
Source/Equation		OUWUA Water Order Database	OUWUA Water Order Database	Measured Flows at Beck's Spill	Estimated based on Concrete Lined Seepage Coefficient (0.24 $ft^3/ft^2/day$)[1]	Water Surface Area * ETo*1.1	OUWUA Water Order Database	Closure--Combination of Unrecorded Spillage and Deliveries to Irrigated Lands--Estimated as Equal Amounts of Spillage and Delivery	
Month	No. of Days	Beat 2 Diversion, (AF)	Recorded Deliveries, (AF)	Measured Spill, (AF)	Seepage, (AF)	Evaporation, (AF)	Recorded Spill (not including Beck's Spill) , (AF)	Unrecorded Deliveries to Irrigated Lands, (AF)	Unrecorded Spillage to Irrigated Lands, (AF)
5	28	3,201	2,143	290	109	8	21	315	315
6	30	4,409	2,842	472	130	11	104	425	425
7	31	4,260	2,991	324	129	11	37	384	384
8	31	3,933	2,560	507	127	10	40	344	344
9	30	3,356	2,148	564	114	8	17	252	252
10	26	2,120	1,259	443	76	4	13	162	162
Total	**176**	**21,279**	**13,943**	**2,600**	**685**	**52**	**232**	**1,882**	**1,882**
Percentage of Diversion			66%	12%	3%	0%	1%	9%	9%

[1]Published seepage rates from lined canal ponding tests vary substantially. Two examples are 0.07 $ft^3/ft^2/day$ for 3- to 4-inch concrete liner with good joint filler (USBR, 1994) and 0.24 $ft^3/ft^2/day$ for "weathered and aged" concrete lining (Worstell, 1976). Much of the lining in Beat 2 fits the "weathered and aged" description, thus, 0.24 $ft^3/ft^2/day$ was selected as the seepage coefficient.

Table 4. Summary of 2006 OUWUA Beat 2 Irrigated Lands Water Balance

	Inflows		**Outflows**								
Source/ Equation	(Recorded Deliveries) + (Unrecorded Deliveries to Irrigated Lands)	Orland CIMIS Station #61	Applied Water Balance Closure (IL)	Rainfall Water Balance Closure	(District Deliveries) * (Estimated Tailwater percent)		Rootzone Model	Rootzone Model	Rootzone Model	Rootzone Model	Rootzone Model
Month	District Deliveries, (AF)	Rainfall (AF)	Deep Percolation of Applied Water, (AF)	Deep Percolation of Rainfall, (AF)	Tailwater, (AF)	Storage Change of Applied Water, (AF)	Rainfall Runoff, (AF)	ET of Applied Water, (AF)	ET of Rainfall, (AF)	Evaporation of Rainfall, (AF)	Storage Change of Rainfall, (AF)[1]
May-06	2,458	261	417	62	492	376	26	1,173	821	26	-675
Jun-06	3,267	40	461	4	653	149	4	2,004	48	4	-19
Jul-06	3,375	0	460	0	675	-6	0	2,245	2	0	-2
Aug-06	2,904	0	242	0	581	-9	0	2,091	0	0	0
Sep-06	2,400	0	196	0	480	15	0	1,710	0	0	0
Oct-06	1,421	16	94	1	284	-108	2	1,151	12	2	0
Total	**15,825**	**317**	**1,870**	**67**	**3,165**	**417**	**32**	**10,374**	**883**	**32**	**-696**
Percentage of Deliveries			12%		20%	3%		66%			

[1]Negative values refer to volumes removed from storage.

described earlier. The simulations indicate that the annual spillage volume at Beck's spill could be reduced by 1,871 acre-feet.

Unrecorded spillage to irrigated lands from the Beat 2 canal system was estimated to be 1,882 acre-feet. The reservoir and related automation has been designed to capture on-farm spillage from the operational benefit zones. The unrecorded on-farm spillage volume in each benefit zone was assumed proportional to the irrigated area in the zone, and the on-farm spillage volume from each benefit zone that could be conveyed to the reservoir was estimated. Totaling the estimates from each benefit zone resulted in a with-project spillage reduction of 945 acre-feet.

On-farm water savings are expected to be modest, resulting from improved surface irrigation practices and from the more rapid conversion from surface irrigation to pressurized irrigation enabled by the proposed reservoir. Together these effects are estimated to reduce tailwater from an estimated 20 percent of deliveries to farm to 16 percent.

The approximately 10-acre area of the proposed reservoir site is part of a 50-acre field that received a total recorded delivery of 116 acre-feet, or 2.29 acre-feet per acre in 2006. With the project, the delivery to this field can be expected to be reduced by the average delivery per acre multiplied by ten acres or 23 acre-feet.

The total estimated spillage and delivery reduction are 3,500 acre-feet. However, evaporation, seepage and spillage at the reservoir are new losses that will occur from the proposed regulating reservoir. These losses are estimated to be 28, 29 and 8 acre-feet, respectively. Subtracting the total new losses from the spillage and delivery reduction and rounding to the nearest one hundred acre-feet provides an expected value of project savings of 3,400 acre-feet (Table 5). Based on confidence intervals estimated for the OUWUA Beat 2 water balance, a 95 percent confidence interval of 30 percent is established for these savings. This can be interpreted as being 95 percent confident that the project savings will fall between 2,380 and 4,420 acre-feet with an expected value of 3,400 acre-feet.

Table 5. Estimated Total Project Water Savings with Confidence Intervals

Targeted Flow Path	Without Project, (AF)	With-project, (AF)	Flow Path Reduction, (AF)	CI[1]
Spillage at Beck's Spill	2,600	729	1,871	7%
Unrecorded Spillage to irrigated lands	1,882	937	945	96%
Tailwater from irrigated lands	3,165	2,504	661	64%
Reduced Deliveries (Reservoir area)	23	0	23	10%
Total Conserved Water			3,500	25%
New Flow Paths with Reservoir				
Reservoir Evaporation	0	28	-28	30%
Reservoir Seepage	0	29	-29	50%
Reservoir Spillage	0	8	-8	10%
Total New Flow Paths (Losses)			-65	0%
Total Conserved Water (Rounded to the nearest 100 acre-feet)			3,400	30%

[1]Confidence Interval

REGULATING RESERVOIR AND LATERAL IMPROVEMENTS DESIGN

Achieving spillage reduction estimates while simultaneously improving, or maintaining, existing service levels requires an integrated lateral and reservoir control strategy. Flow changes must be passed down Lateral 210 to the reservoir and from the reservoir to Beck's Spill without significantly changing delivery flows to growers along the way. Four improvement scenarios were defined targeting water savings in various combinations of the benefit areas. Estimated costs for the improvements necessary under each scenario were combined with water savings estimates for the targeted benefit areas to compute the annual cost of the water savings generated. Scenarios 2 and 4 cost the same per acre-foot of spillage and tailwater reduction, however, the estimated spillage and tailwater reduction for Scenario 4 was 700 acre-feet per year more than Scenario 2 (Table 6).

Table 6. Summary of Economic Analysis of Improvement Scenarios

Scenario	Benefit Areas	Capital Cost + Contingency ($)	Annual Cost ($/yr)	Annual Spillage and Tailwater Reduction (AF)	Unit Cost ($/AF)
Scenario 1	2	$ 2,074,160	$ 143,183	2,200	$ 65
Scenario 2	2,4, and 6	$ 2,146,710	$ 149,106	2,700	$ 55
Scenario 3	1 and 2	$ 2,441,734	$ 173,191	2,600	$ 67
Scenario 4	all	$ 2,586,834	$ 185,036	3,400	$ 54

Scenario 4, identified as the preferred improvement configuration, requires a reservoir of at least 35 acre-feet and upgrade of 23 check structures on Lateral 210. The regulating reservoir site and grading plan includes horizontal coordinates, critical water surface and embankment elevations and earthwork quantities. Improvements for check structures were required to maintain delivery flow rates within plus/minus five percent while passing 12 cfs (one head) more or less down the lateral to the reservoir. Long crested weirs, flap gates and automated gates were all options that could meet the requirement for maintaining delivery flows while passing flow changes down the lateral. Flap gates or long crested weirs were preferred because of OUWUA's staff experience in their construction, maintenance and operation. Flap gates are less expensive to construct, so they were used where there was sufficient head available. These criteria resulted in selection of six 2-bay long crested weirs, 14 single bay long crested weirs, one flap gate and one automated slide gate.

Automated overshot gates with flow measurement and the capability to remotely program the time for a flow set point change will be installed at the head of Lateral 210 and at the headings of four sub laterals branching off Lateral 210. Similar automated overshot gates will be used at a flow control point in Lateral 210 at the reservoir inlet and for the two reservoir outlets.

A Doppler flow measurement device is planned for just downstream of the reservoir to allow the flow at this location to be controlled by changing the reservoir outlet gate. A ramp flume, or Replogle flume, will improve measurement accuracy at Beck's Spill.

Estimated construction costs for the preferred improvement scenario were $2.59 million. This cost does not include project management and engineering services during construction.

SUMMARY

A verification-based modernization planning process estimated that a regulating reservoir and associated lateral improvements would save 3,400 acre-feet with a confidence interval of 30 percent at an estimated cost of $54 per acre-foot. These estimated benefits, based on a proposed operations plan with the improvements, were derived from measured spillage data and a water balance of the defined benefit areas within Beat 2. Near-final designs and cost estimates were prepared for the regulating reservoir and associated lateral improvements and utilized to select a least-cost preferred alternative.

Five preliminary regulating reservoir locations were evaluated against defined criteria resulting in the selection of a location in Beat 2 for detailed analysis. Existing operations were characterized leading to proposed operations with the regulating reservoir and defined benefit areas within Beat 2. The regulating reservoir and associated lateral improvements were selected and approved for implementation funding to save 3,400 acre-feet with a confidence interval of 30 percent at an estimated cost of $54 per acre-foot. Final designs are nearly complete, environmental approvals and permits have been obtained and construction is expected to begin later this year.

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INFRASTRUCTURE INVENTORY AND GIS MAPPING FOR CANAL IRRIGATION DELIVERY SYSTEMS

Richard L. Belt[1]
Stephen W. Smith[2]

ABSTRACT

A comprehensive inventory of canal infrastructure and subsequent mapping is critical to respond to challenges facing irrigation companies and districts. This seems self-evident and obvious, but this information is seldom gathered and maintained because present-day irrigation entities are tasked with operation and maintenance of canal infrastructure that can be over one hundred years old. Typically, there are significant financial constraints and companies operate in a "crisis management" mode, where only the most pressing needs are addressed as they arise.

Modern irrigation in the western United States is facing many new challenges, ranging from water conservation and environmental considerations to urbanization within the system service areas. Additionally, recent drought conditions, the rising costs of labor and fuel, and the reduction in cost of canal technology have prompted many irrigation districts and companies to consider canal modernization. Accurate infrastructure mapping and implementation of geographic information system (GIS) technology is the first step in developing a comprehensive approach to these challenges. Mapping efforts are enhanced through the use of GIS and global positioning system (GPS) technology combined with hand-held computing.

The GIS and infrastructure mapping supports the efforts to address these challenges, through identification of critical structures, priority improvements, and support of desktop analysis, modeling, and planning. The GIS can also be further enhanced through the development of tools to streamline operations and integrate with other systems, such as data management, water ordering and billing, and institutional planning.

INTRODUCTION AND BACKGROUND

Agricultural irrigation in the western United States was characterized by the development of storage reservoirs and canal systems for conveyance and distribution beginning at least 150 years ago. Today irrigation systems in the western United States range from individual irrigators irrigating several hundred acres to the Imperial Irrigation District which serves approximately 450,000 acres in southeastern California.

Today, irrigation companies and districts are faced with a number of challenges driven by both internal and external forces. Irrigation infrastructure in use today is often past its

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useful lifespan, contributing to system-wide inefficiencies in the use of both water and human resources. Irrigation systems have evolved throughout their history to meet the demands of their water users and, often, little effort was made to keep accurate mapping of minor or abandoned structures. Historic irrigation infrastructure is “lost” as a result of lost institutional memory and can exacerbate system inefficiencies through uncontrolled leakage and seepage.

External forces, such as urbanization and increasing pressure to conserve water for environmental, municipal, and industrial uses, further challenge historic irrigation practices and water use by irrigation entities. The West is home to most of the nation’s fastest growing states and cities. Often, people in these communities are new to or detached from an area’s agricultural and irrigation traditions, leading to increased scrutiny of irrigation practices and conflict. Conflicts between agriculture and environmental concerns have led to several well-publicized regional crises. The unique character of irrigation systems throughout the West further complicates these issues. A patchwork of state laws, customs, and historic operations combined with the unique geography and regional agricultural demands has led to the development of irrigation systems in all shapes, sizes, and operational complexity. One size does not fit all!

On top of it all, irrigation entities struggle with the cost of addressing and adapting to these pressures. Agricultural producers are often unable to afford the higher assessments necessary to address the myriad pressures facing their irrigation water provider. Many entities operate in a continual crisis management mode and are only able to respond to their most dire needs, while others continue to make interim improvements to their system, foregoing the high costs of meeting their true rehabilitation needs.

To adequately address these challenges, irrigation entities must have detailed understanding of their irrigation infrastructure, water rights, on-farm irrigation systems, cropping patterns and water use, return flows, land-use plans of the neighboring (and encroaching) urban areas, easements, rights-of-way, construction activities of local government and commercial entities, local environmental issues, stormwater, and liability due to flooding and injury, and myriad other issues. Further staff burdens result from addressing the needs, concerns, and requests for information from irrigators under the system, local governments, environmental groups, homeowners groups, realtors, developers, etc. These issues are much the same as are faced by local utilities, but irrigation entities often have significantly less budget, staff, or in-house expertise in these matters.

These pressures and the availability and decreasing cost of technology have begun to allow irrigation entities to implement much needed improvements which help confront some of these challenges. New lining and piping technologies, structures with gates actuated using supervisory control and data acquisition (SCADA) technology, and the ability to inexpensively and accurately measure flow and alert personnel to alarm conditions have begun to allow irrigation entities to address some of the external pressures that they face. The reduction in cost of personal computers and software has also made it affordable to implement geographic information systems (GIS) for irrigation entities. GIS, and the associated data-gathering efforts, is the first step to planning a comprehensive response to the issues challenging an irrigation entity.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems are a powerful software tool used to store, analyze, manage, and display geographically-referenced data (ESRI, 2009). GIS features a suite of customizable tools and applications which allows users to perform many types of analyses and display the results in a geographic context which is both easy to understand and communicate to others. Most fully-featured GIS software includes powerful programming tools in addition to the mapping and database functionality, which allows the customization of GIS to a huge number of specific applications.

Many irrigation entities do not have sufficient knowledge of their existing operations to begin to address the challenges cited previously. Often, there is not an accurate, up-to-date map of the irrigation system which depicts currently used infrastructure in the context of the service area and surroundings. It is important that an irrigation entity understand basic GIS concepts, existing and potential future challenges to irrigation operations, and have a vision for what the future GIS tools and information may be used for under the system. This understanding will help define the acquisition of data and drive the development of appropriate tools for use in analyzing and accessing the data.

Development of a GIS for an irrigation entity involves several steps (Figure 1):

1. Identification of appropriate GIS and mapping goals.
2. Selection of a suitable software platform.
3. Acquisition of publically-available data and mapping.
4. Collection of relevant data about the system.
5. Development of tools to use or access the data.
6. Regular database maintenance and updates.

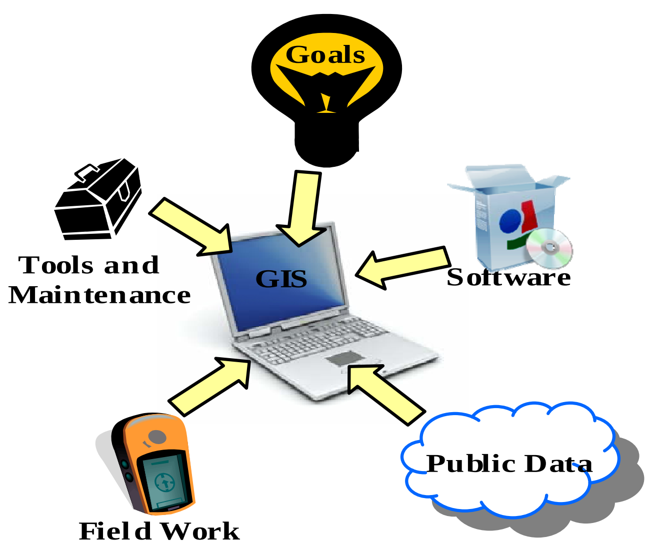

Figure 1. Development of GIS for Irrigation Applications

Identification of GIS and Mapping Goals

The most critical step in the development of any GIS or mapping project is to adequately understand the goals that the effort is intended to address. Common goals for the development of a GIS or irrigation system mapping may include:

1. Aid for personnel training and succession planning.
2. Support planning for rehabilitation or modernization efforts.
3. Support system-wide water budget analysis to quantify consumptive use or return flow patterns.
4. Managing urbanization within the system service area.
5. Implementation of an infrastructure management system.
6. Tool to educate irrigators or other members of the community about the irrigation system and its importance in the community.

The goals identified will help to guide the rest of the process, in particular the data collection effort. The data collection effort is the most time-consuming and expensive aspect of GIS implementation. Detailed understanding of the goals and future uses of the GIS will focus on the critical data and ensure that the appropriate data are collected.

Selection of a Suitable Software platform

There are several GIS software packages currently on the market which may be suitable for use by irrigation entities. GIS software is made available through two routes; proprietary software sold through license, or open source (non-commercial) software. Commercial software includes many of the well-known, widely-used GIS packages including ArcMAP and ArcINFO by the ESRI and Map3D by Autodesk. There are a number of other commercial GIS software packages which may be appropriate to irrigation district applications. This software ranges in price and capability, and is typically characterized by the need to purchase and maintain a license, as well as the availability of technical support and training in the use of the software. The examples given in this paper were prepared using the ESRI ArcMAP software. ESRI products are the industry-standard GIS software and are widely used.

Open-source software is non-commercial software that is typically developed and distributed free or for a nominal charge. This software is typically not licensed and can be downloaded from the internet. GRASS, prepared by the U.S. Army Corps of Engineers, is a widely-used, high capability open-source GIS. There are a number of other open-source GIS software packages which may be useful in these applications. This software typically includes a written manual, but typically does not include technical support or training.

Acquisition of Publically-Available Data and Mapping

There are many types of spatial data that may be relevant to the development of a suitable GIS for an irrigation entity. These data may include:

1. USGS quadrangles.

2. Aerial photography covering several years (USGS DOQQ imagery or NAIP imagery are widely available).
3. Satellite Imagery (infrared and other bands may be useful in determining irrigated areas).
4. Soils mapping by the NRCS.
5. USGS Digital Elevation Models (DEM).
6. TIGER (Topologically Integrated Geographic Encoding and Referencing) data collected by the U.S. Census Bureau which include roads, buildings, rivers, lakes, etc.
7. Cropping patterns.
8. Land-use mapping prepared by federal, state, or local agencies.

These data and many others may be available through a variety of sources including federal, state, and local government agencies, GIS clearinghouse websites, and commercial websites. Typically, these data are georeferenced to a known horizontal coordinate system and vertical datum (if applicable), which allows the GIS software to correctly locate the data in space and relative to other data that may have been acquired.

Collection of Relevant Data about the System

Collection of field data is typically the most critical and costly element in the development of a useful GIS for an irrigation entity. As described above, irrigation system mapping, if it exists, may be out-of-date, generally insufficient for needs, and not reflective of current surrounding infrastructure, land uses, or irrigation system infrastructure. Irrigation entities can benefit from a detailed knowledge of infrastructure on their canal systems, ranging from river diversion to farm turnout and including infrastructure (i.e. road crossings) that may be owned by third-parties.

There are a variety of hand-held inventory-grade and survey-grade devices which facilitate these data gathering efforts. Typically, these devices contain integrated global positioning system (GPS) capabilities which allow for the collection of coordinate and elevation data at desired locations. Often, these devices also employ a mobile device-based version of the GIS software (e.g. ArcPAD for ESRI-based systems) which allows for the development of the system GIS in the field. Some software allows for the development of an input form or "questionnaire" which prompts field personnel to gather particular data about structures included in the survey and can include "pull down" menus to increase data collection speed and accuracy. Additionally, inaccurate linework contained on the publically-available base mapping can often be corrected in the field by personnel observing the particular feature, resulting in highly-accurate mapping.

Development of Tools to Use or Access the Data

Once data has been collected and assembled, as described above, the GIS is ready for use (Figure 2). Depending on the GIS goals, the standard query and analysis tools may be sufficient for the user's needs. These tools are often suitable to specific, Boolean queries (i.e. show me all structures in "poor" condition on the "Smith" lateral). Other, more sophisticated analyses are also available using tools that may be available as add-on modules (i.e. show me all "turnouts" that are contained in the boundary of the proposed "Smith PUD" development. This analysis would require that fields served by turnouts be identified and intersected with the location of the Smith PUD provided by the local government). These basic analyses and queries may be sufficient to allow the irrigation entity to employ GIS to manage the system and meet many of the goals described above.

There is no limit on the number and types of tools or interfaces that could be developed to interact with the data that is assembled. It is possible to develop linkages between the GIS database and other data management programs which would allow the development of a virtual "file cabinet" for storage and retrieval of data based on geographic location. This would allow all data related to a particular turnout, field, or structure to be available at the click of a button and would save time currently spent searching in physical file cabinets. The amount of information which could be made available in this manner is limited only by the budget (data availability could be phased to meet budget constraints), computer storage space (approximately $100 per terabyte currently), and the imagination or needs of the end user.

These tools could also include productivity enhancements for irrigation system personnel, such as mailing list generators (i.e. identify an upstream structure and generate a list of downstream users to notify about planned maintenance) or an email tool which packs user selected data to respond to outside requests for information (i.e. a developer would like mapping of irrigation system easements and infrastructure on a parcel).

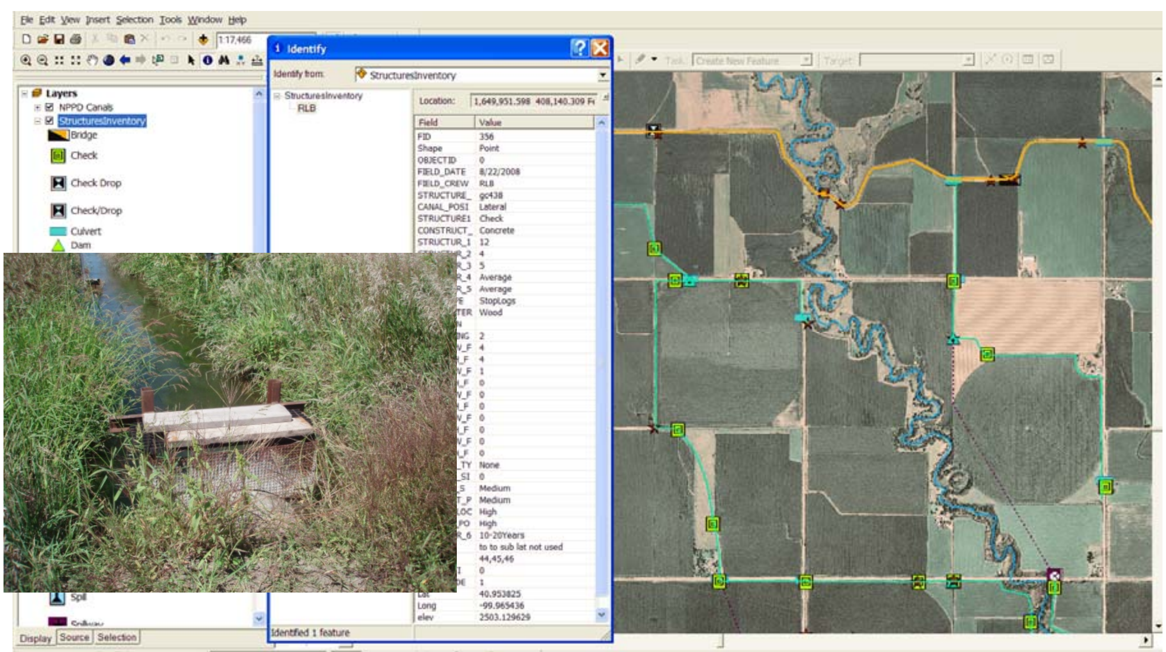

Figure 2. GIS screen capture showing canal inventory and structure database query.

Regular Database Maintenance and Updates

Depending on the GIS goals and the size of the irrigation entity, development of a GIS can be a significant investment of time and money. This investment is protected and extended through regular updates and maintenance of the database. Often, third-party data is updated annually and the data is available on an ongoing basis via subscription. Irrigation system data should be updated as-needed, depending on the implementation of infrastructure improvements or other relevant changes to the system. The ultimate utility of this tool, as with other types of tools, depends on the accuracy and the timeliness of the data contained within.

NEXT STEPS

The GIS is a tool that can be used to assist with the management of numerous issues under a typical irrigation system. The specific applications depend on the system goals, data availability, sophistication of the operator and tools, irrigation system size and complexity, and the types of challenges facing the entity. As described previously, one size does not fit all, so a series of potential applications will be illustrated.

Planning for Canal Modernization

Canal modernization is a generic term for the variety of infrastructure and automation improvements that often result in canal operations which conserve water and human resources. Often these studies are completed by consultants who do not have detailed, operational knowledge of the canal system at the time that the study begins. Effective canal modernization planning requires detailed understanding of canal operations and the external challenges that may be confronting the irrigation entity (Figure 3). Detailed mapping and infrastructure data is critical to the development of adequate canal modernization planning. The following basic data are useful in these support tools:

1. Aerial photography. Aerial photography conveys significant information about the nature of a canal and its surroundings.

2. USGS quadrangle or other topographic data. Topography is a critical consideration in the planning for communication systems which often accompany SCADA systems.

3. Basic irrigation system data. Information regarding service area, canal alignment, check and turnout location, canal spills and returns, flow measurement, etc. is critical to understanding the basic canal system operations.

4. Detailed irrigation infrastructure data. Detailed structural information (i.e. structure type, structure condition, gate type, structure importance) is critical to development of improvement priorities, identification of the appropriateness of retrofit versus replacement, etc.

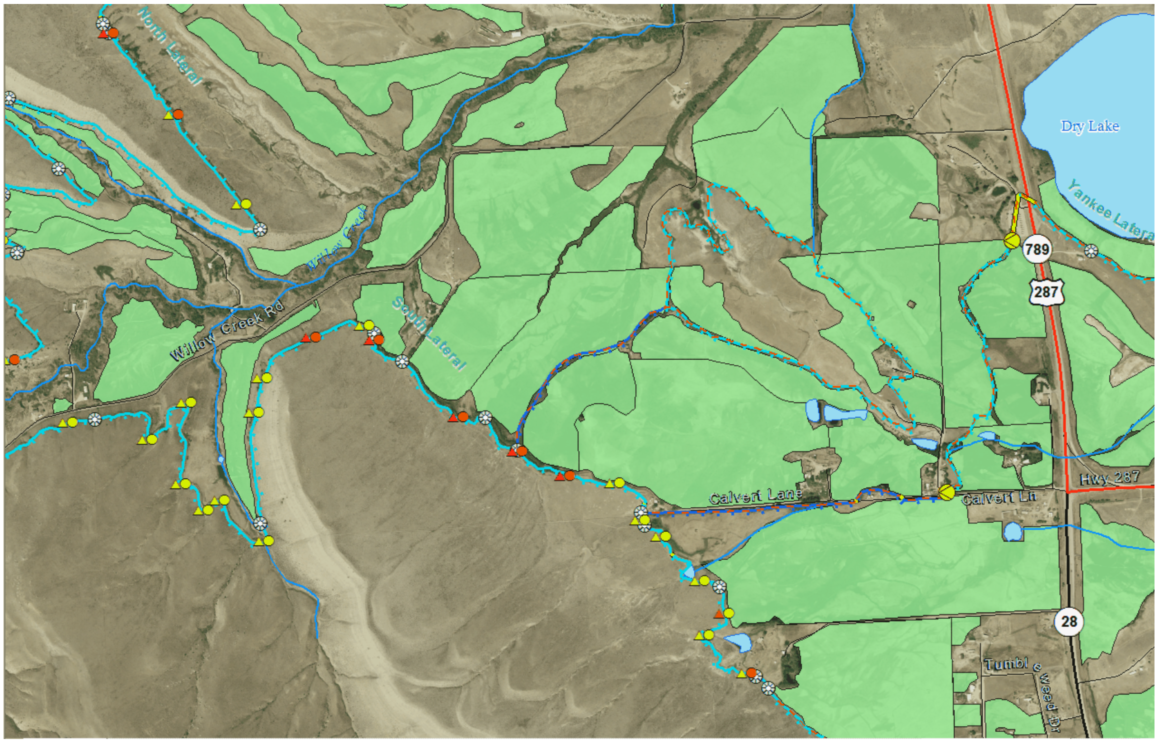

Figure 3: GIS created map showing canal and bank condition, irrigated lands, and structures.

Responding to Urbanization

Responding to urbanization pressures is a common external challenge facing many irrigation entities in the western U.S. The specific nature of this challenge varies by region or system, but the challenge has many common features. It is common for irrigation entities to have no idea about the planning activities and regulations of local governments, and for local governments and developers to have a limited understanding of irrigation operations, infrastructure, and needs. Often this lack of information is manifested as a conflict between these interests over development of a parcel located within the irrigation service area or adjoining part of the irrigation distribution system. Inevitably, this conflict occurs well into the development process, potentially resulting in costly redesign or even legal actions. It is essential that irrigation entities approach local government, or vice versa, with needs and concerns related to urbanization in the vicinity of irrigated ground or infrastructure. Ideally, the irrigation entity and local government can work together to ensure that all proposed development meets the needs and requirements of both entities during the planning process.

Local government entities are often unaware of the extent of irrigation infrastructure and service area. Providing local government entities with the following information may assist them in providing adequate information to prospective developers to minimize the potential for future conflict:

1. Basic irrigation system data. Information regarding service area, canal and lateral alignment, check and turnout location, canal spills and returns, flow measurement, etc. is critical to understanding the basic canal system operations.

2. Irrigation system property data. Recorded or prescriptive easements for canal conveyances, access and maintenance easements, and other property matters are essential. Some easements may not be recorded so this information is invaluable in preventing future conflicts.

3. Irrigation hazards mapping. Canal leakage or overtopping due to unusual or unforeseen circumstances has been a known hazard since the development of irrigation canals. Often these hazards have been manageable and have not caused significant damage in a historically agricultural area. It may be useful to provide information about known areas of concern to project developers to protect the irrigation entity against increasing risk of significant damage following urbanization.

GIS data will often be desired by government entities to complement their own data. In this situation, long term reciprocal sharing of data can become a routine and desired outcome.

Documentation of Beneficial Use

Many Western states allow water rights to be changed to other locations or uses, or may require that beneficial use be documented. Development and maintenance of a GIS is an excellent vehicle for gathering, storing, and managing data which are important to these efforts (Figure 4). Once gathered, these data can be used to show irrigation, to support water budget analyses, etc. There are several basic pieces of information which are critical to these efforts:

1. Aerial photography. Aerial photography over many years provides simple evidence of irrigation that is essential to many water rights proceedings. It is also very useful in documenting land use changes, a “timeline” of urbanization, and other information. A picture is worth a thousand words, as they say.

2. Soil mapping. NRCS soil mapping is typically a GIS-ready product that can be acquired free of charge. This product provides valuable information about the soil reservoir and productivity that is useful for a wide variety of applications.

3. Cropping patterns and irrigation methodology. This information can be reported by irrigators or obtained from the Farm Service Agency. This basic data is critical to determining the consumptive use of water under the system, which is often a component of most water rights proceedings.

4. Basic irrigation system data. Information regarding service area, canal alignment, turnout location, canal spills and returns, other area water rights, etc. is often critical in these types of proceedings.

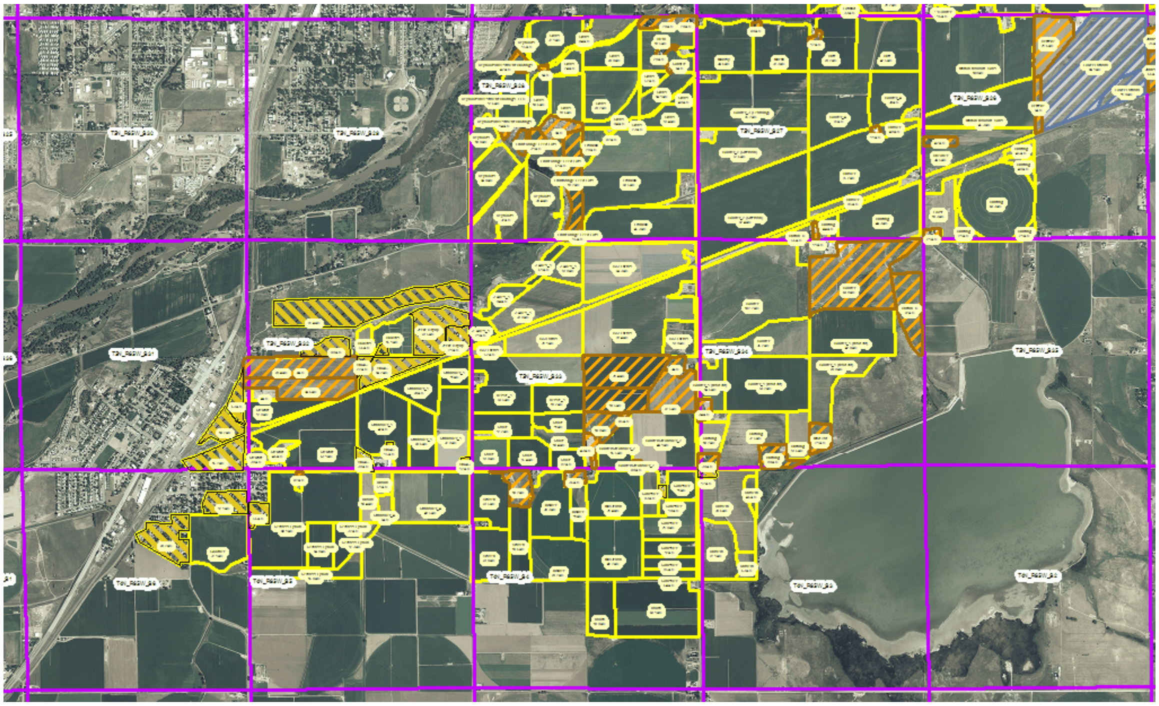

Figure 4: GIS-based analysis in support of historic consumptive use determination.

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A STUDY OF ADDITIONAL DRAINWATER REUSE FOR THE SUTTER BASIN

Brett M. Isbell, P.E. [1]

ABSTRACT

Farmers in the Sutter Basin, in the Sacramento Valley of California, do not have sufficient irrigation supply to meet crop needs during peak irrigation demand and during years with surface water allocation restrictions. To help meet these needs, Reclamation District 1500 examined the viability of expanding its existing drainwater reuse system.

Drought and reduced surface water allocations, which are partly attributed to ever-more-stringent environmental concerns and regulations, have markedly increased the hard-to-quantify socioeconomic value of a reliable water supply. Basin farmers have a sense of urgency to establish a supplemental irrigation supply. Expanding the drainwater reuse system for a supplemental irrigation supply will increase water delivery reliability in the Sutter Basin. Approximately 68,000 irrigated acres and over 500 miles of surface drainage channels encompass the study area, where rice is the predominate crop. This study highlights the need to identify supplemental irrigation sources in the absence of extensive master planning data. This study relied on stakeholder input to identify operational and management constraints and to develop specific evaluation criteria. Drainwater availability was inversely proportional to downstream irrigation demand in the Sutter Basin, which required special engineering consideration. The study found that drainwater quality concerns can be mitigated by (a) reusing drainwater upstream of the connate water zone, (b) blending drainwater with surface diversion water, and (c) implementing water quality monitoring program tailored to the recommended alternative. Two service-area-scale drainwater reuse alternatives are recommended to collectively provide up to 20,000 acre-feet of supplemental irrigation supply annually. Project implementation would help offset surface diversion shortages and increase water delivery reliability in the Sutter Basin.

INTRODUCTION

This study examines drainwater reuse in the Sutter Basin (Basin), which is located in the Sacramento Valley of California (see Figure 1). Approximately 68,000 irrigated acres and over 500 miles of surface drainage channels exist in the study area. The combination of natural topography and constructed levees in the study area requires that all excess surface water be collected and discharged from the Basin into natural waterways: this is managed by Reclamation District 1500 (RD 1500).

Currently, Basin farmers do not have sufficient irrigation supply during peak irrigation demand and during years with surface water allocation restrictions. These shortages have worsened since 2004 when the annual full allocation for Sutter Mutual Water Company (SMWC), a Sacramento River Settlement Contractor, was reduced to 226,000 acre-feet. SMWC provides approximately 75 percent of surface irrigation water in the Basin

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depending on the water year. Furthermore, SMWC's State Ranch Bend service area, which is isolated from other conveyance networks, consistently has water shortages where gross irrigation demand exceeds delivery capacity. Also, the Basin has what is commonly referred to as tailender problems: flexibility and reliability of irrigation deliveries are compromised toward the downstream end of irrigation laterals. All surface drainage water must be pumped out of the Basin. This can be costly.

This study highlights the need to identify supplemental irrigation sources in the absence of extensive master planning data. The study did not include extensive data collection, nor was it a comprehensive appraisal of conveyance infrastructure; and the irrigation delivery system was not specifically assessed. Also, this study did not address reducing connate water inflows as discussed in previous reports (Cal Poly ITRC 1999 and 2000). This study addresses the need to expeditiously identify a supplemental water supply.

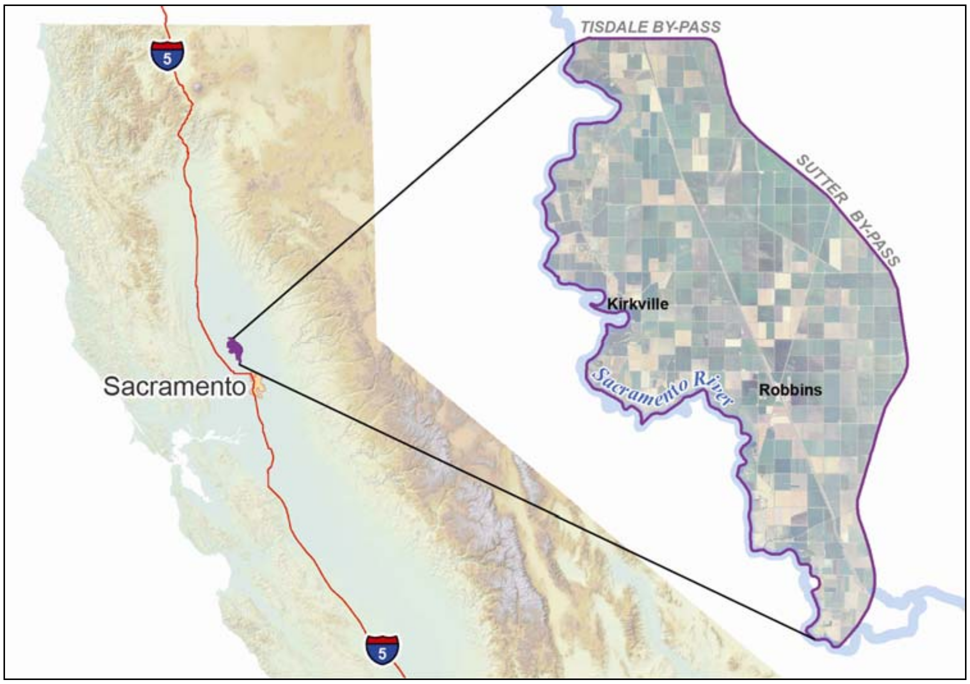

Figure 1. Sutter Basin vicinity map

EXISTING CONDITIONS

Drainage Overview

RD 1500 collects and manages drainwater from all land in the Basin. Drainwater is conveyed out at one location: the Karnak Pumping Plant at the southernmost end of the Basin. Drainwater either flows by gravity or is pumped out of the Basin at this location depending on the water levels in RD 1500's main drain and the Sacramento River. Pumping of drainwater outflow is typically required during the irrigation season. Average Basin outflows are summarized in Figure 2. Drainwater outflow includes drainwater during the irrigation season, runoff during the rainy season, and groundwater flows into some of the drains, particularly in the connate water zone as found in previous studies (U.C. Davis, 1970 and 1972).

The main drain, which flows generally north to south, bisects the Basin. Drainwater is conveyed to the Karnak Pumping Plant via the main drain. An elaborate network of both drain laterals and sublaterals conveys drainwater to the main drain from both the east and west. A few row-crop fields in the Basin have tile drains to facilitate root zone drainage, but overall tile drains are not prevalent. Under special conditions farmers use private pumps to reuse drainwater from the RD 1500 drain network but the practice is not common.

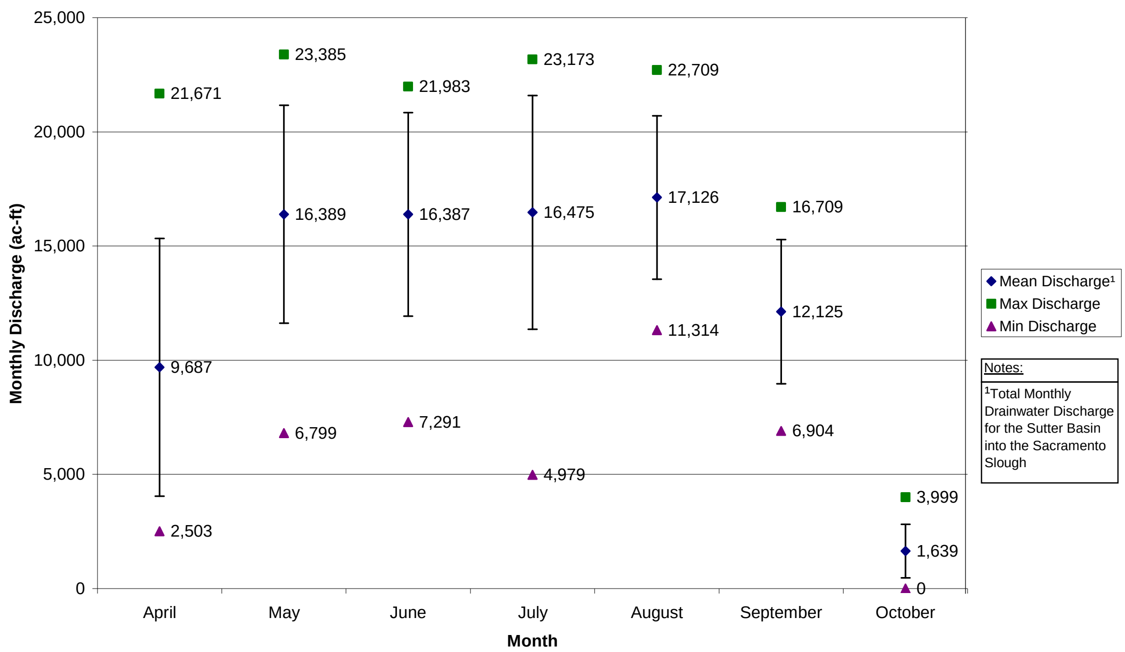

Figure 2. Basin drainwater discharge, April through October (1991 – 2000).

Water levels in drainage laterals are controlled using flashboard risers. Drainwater is checked up during the irrigation season to provide backwater hydraulic gradients for the existing drainwater recycling pumps. Even though high drainwater levels might reduce connate water inflow, drainwater levels should not be raised too high because the high water table can damage row and field crops. Once the flashboard checks are installed, they are seldom adjusted during the growing season. Checks are removed after the growing season to facilitate drainage and leaching of the root zone and maximize drainage capacity for flood control.

Table 1. Overview of Sutter Basin Water and Drainwater Entities.

	SMWC	PMWC	Rimlanders	RD 1500
Service Area (acres)	51,200[a]	3,000[b]	13,800	68,000[c]
Average Annual Surface Water Diversion(acre-feet)	200,562[d]	5,659[e]	Not Available	154,896[f]
Average Annual Drainwater Reuse Volumes (acre-feet)	15,000[g]	8,000[h]	Not Available	
Crops[i]	Rice	Rice	Not Available	
	Grain	Safflower		
	Tomatoes	Wheat/Barley		
	Safflower	Tomatoes		
	Sunflower	Wild Rice		
	Other	Other		

Notes:
a. From SMWC records
b. From PMWC records
c. Source: "Reclamation District No. 1500 resource study" performed by the NRCS in 1996
d. Average annual diversion of Sacramento River water for years 2000 through 2007
e. Average annual diversion of Sacramento River water for years 2002 through 2007
f. Average annual discharge of drainwater into the Sacramento River for the years of 1991 through 2000
g. From "Reclamation District No. 1500 resource study" performed by the, NRCS in 1996
h. Average annual drainwater recycled volume from PMWC records for years 2002 through 2007
i. Prioritized by most acreage

Irrigation Overview

Two water companies serve the Basin: SMWC and Pelger Mutual Water Company (PMWC). Additionally, some farmers have independent irrigation water sources and are referred to as Rimlanders. The primary source of irrigation water in the Basin is the Sacramento River. Four main pumping plants and several smaller, private pumps discharge surface irrigation water into the Basin from the Sacramento River. Groundwater wells, particularly on the west side of the Basin, are used as needed during times of limited surface water supply. Table 1 summarizes the acreages and diversion data for water and drainwater entities in the Basin.

Sutter Mutual Water Company. SMWC delivers water to approximately 51,200 acres. Three pumping plants on the Sacramento River serve three SMWC service areas. Average annual diversions are presented in Table 1. The Tisdale Pumping Plant discharges water to the Tisdale Canal with distribution to the West, East, and Central Canals and their laterals. This is the largest service area totaling 42,900 acres on both the west and east sides of the main drain. The State Ranch Bend Pumping Plant supplies water to the State Ranch Bend main canal and its laterals. This service area is approximately 5,700 acres. The Portuguese Bend Pumping Plant discharges water to the Portuguese Bend main canal and service area of 2,600 acres. Total diversions from the Sacramento River are summarized in Figure 3. On average, nearly 90 percent of irrigation diversions occur from May through August. The greatest year-to-year variations in SMWC irrigation deliveries occur in May and June.

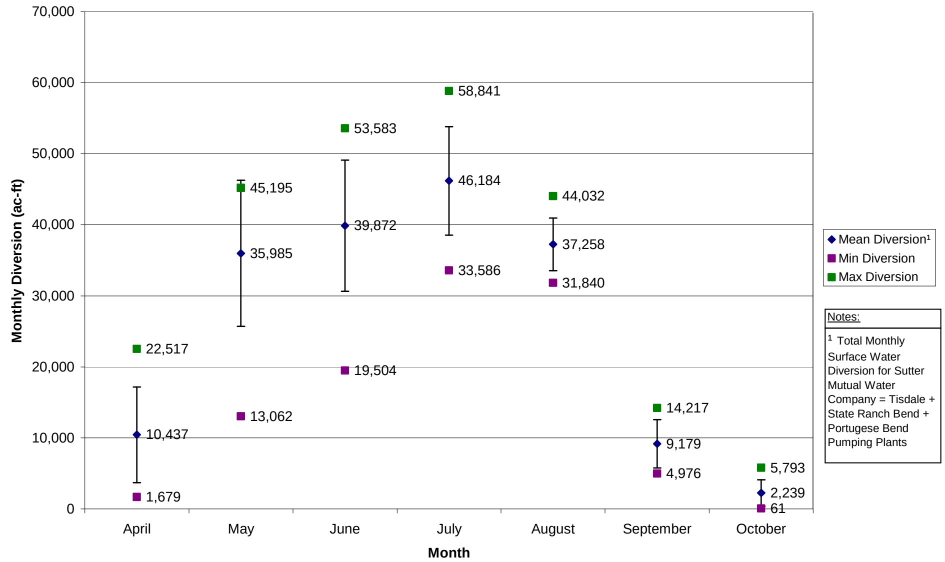

Figure 3. SMWC diversions (1991 through 2000).

The State Ranch Bend service area requires special consideration because it consistently experiences irrigation demands that exceed the irrigation delivery capacity. The bottle-neck is the State Ranch Bend pumping plant: it cannot pump enough water to meet peak irrigation demands. The State Ranch Bend conveyance infrastructure has capacity for additional flow, however.

SMWC operates eight drainwater recycling pumps in the Basin. These recycling pumps convey drainwater directly into adjacent irrigation canals. Additionally, SMWC utilizes portable drainwater recycling pumps to relieve problem areas. Currently, the approximated volume of recycled drainwater is 15,000 to 36,000 acre-feet annually (NRCS, 1996 and SMWC records).

Pelger Mutual Water Company. PMWC delivers water to approximately 3,000 irrigated acres. A pumping plant on the Sacramento River discharges water to the PWMC water distribution system. PMWC operates six permanent and one portable drainwater recycle pumps. These recycle pumps convey drainwater directly into adjacent irrigation canals. Currently, the approximated volume of recycled drainwater is 5,400 to 10,000 acre-feet annually.

Rimlanders. Rimlanders are individual land owners who pump their own irrigation water, primarily directly from the Sacramento River. They do not purchase surface irrigation water from a water purveyor. Water reuse specifically for Rimlanders was not evaluated in this study. However, drainwater from Rimlander’s fields that enters the drainage channel network is managed by RD 1500 and is therefore available for reuse.

Basin Characterization

The Basin was divided into three sub-basins and average drainwater flow data were evaluated. The estimated average Basin-wide drainwater ratio during the irrigation season (May through August for years 1991 through 2000) was 250 acres per 1 cubic foot per second (cfs) drainwater. Drainwater flow measured at three locations on July 22, 2008 verified this approximation.

Cropping Patterns and Effects on Drainwater Availability. Rice has been the predominant crop in the Basin over the past several decades as listed in Table 1. Cropping patterns are subject to change, which can impact the timing surface drainage flow and drainwater availability. However, Figure 4 shows no direct correlation between total irrigation diversions and drainwater outflow, and no direct correlation between rice acreage and total drainwater outflow for the available data. Therefore, no service area drainwater flow adjustments were made as a result of cropping patterns.

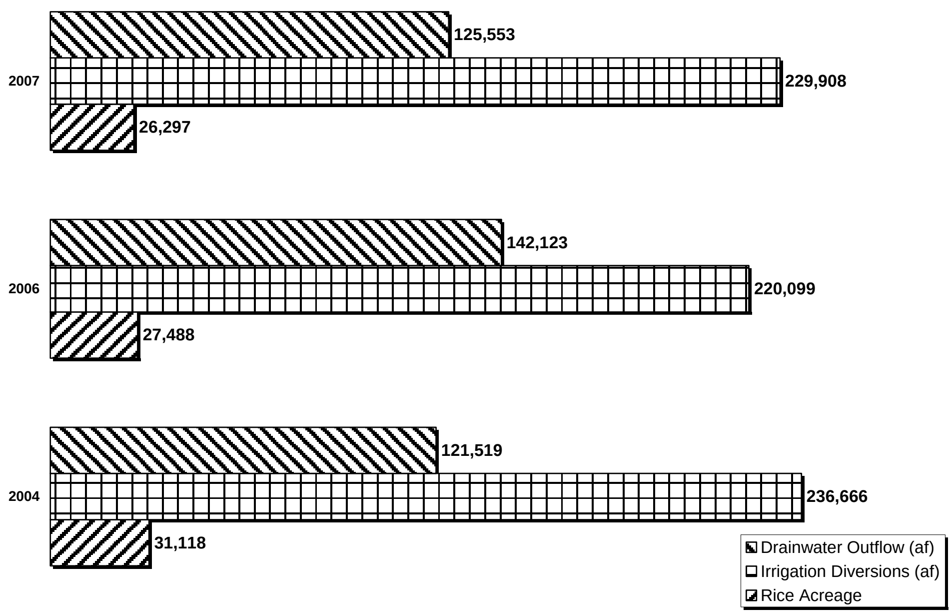

Figure 4. Drainwater Outflow during the Irrigation Season compared to Irrigation Diversions and Rice Acreage.

Drainwater Quality. The Basin water quality target for irrigation deliveries is 750 milligrams per liter (mg/L) maximum total dissolved solids (TDS). Previous studies highlighted drainwater quality concerns for reuse, especially lower in the system (NRCS, 1996; Tanji et al, 1975; Henderson et al, 1972). Limited reconnaissance-level water quality measurements in July 2008 indicated that drainwater is of sufficient quality for reuse, particularly if the drainwater source is upstream of the connate water zone and if drainwater is blended. Blending drainwater with water diverted from the Sacramento River further reduces the salinity.

Drainwater Reuse and Connectivity between Water Purveyors. Physical features of the Basin create connectivity between the operations of irrigation delivery systems and the drainage network. Examples of this connectivity follow:

- All surface water runoff (both precipitation and irrigation origin) enters the RD 1500 drainage system
- Independent water users contribute drainwater to RD 1500 drainage channels
- Drainwater levels affect growing conditions in adjacent fields
- Some drains have bidirectional flow, depending on point-source magnitudes and flashboard riser check elevations

These interdependencies influenced reuse categories and alternatives, which are discussed in the following section.

ALTERNATIVE DEVELOPMENT AND EVALUATION

Basin farmers have a sense of urgency to establish a supplemental irrigation supply. Although drainwater reuse in the Basin is not a new idea, and in fact it is currently practiced, limited data were available. There were few data available on lateral drainwater flows, channel elevations and cross sections, and drainwater quality variability. Stakeholder input and a logical approach to identifying drainwater reuse options were therefore critical in this study. Drainwater reuse categories were identified initially, followed by more detailed alternatives. In addition to field visits and staff interviews, collaborative ideas were shared during two stakeholder workshops.

After initial data collection and research, drainwater reuse categories were developed and presented at a stakeholder workshop. The preferred drainwater reuse category was that of the service-area magnitude: that is, a drainwater reuse system of a magnitude that would convey drainwater from a source to multiple field groups for irrigation. This magnitude is smaller than a previously studied Basin-wide centralized pump-back system, which became infeasible and cost prohibitive. See the drainwater study by Laugenour and Meikle (1997) for more information on centralized pump-back system alternatives. At the same time, the preferred category is larger than localized drainwater reuse like the existing drainwater reuse systems where drainwater is pumped from the source directly to an adjacent field or canal. The evaluation criteria in the following subsection highlight considerations that may be pertinent to other drainwater reuse studies.

Constraints and Evaluation Criteria

At the north end of the Basin, there is ample downstream irrigation demand and elaborate conveyance infrastructure to make irrigation deliveries. Conversely, there is little drainwater available for reuse at the head of the irrigation system. The opposite is true at the southern end of the Basin where there is substantial drainwater available for reuse but a small amount of acreage and limited conveyance infrastructure. Balancing this inversely proportional relationship, which is illustrated in Figure 5, between drainwater availability and irrigation demand without an extensive and costly centralized pump-back system was required when developing alternatives.

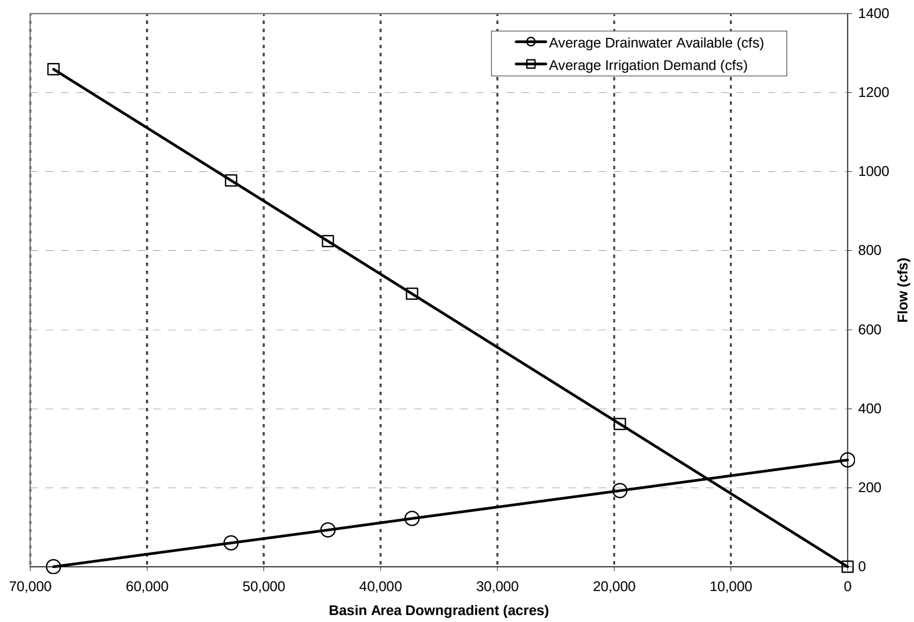

Figure 5. Inverse relationship between irrigation demand and available drainwater.

Other criteria included providing drainwater reuse to multiple service areas; identifying a reliable drainwater source; verifying adequate irrigation demand for sustained reuse deliveries; providing equitable irrigation deliveries; and minimizing drainwater outflow pumping costs.

Generally, reusing drainwater makes surface diversion water available for delivery elsewhere. This increases reliability of irrigation diversions for all Basin users. Therefore, when drainwater is pumped back into an irrigation lateral there should be sufficient downstream irrigation demand such that the drainwater can be consistently reused during the irrigation season. This maximizes the benefit of the available drainwater. Presumably, cropping patterns, cultural practices, year-to-year weather variations, evapotranspiration demands, and on-farm irrigation efficiency can influence the correlation between drainwater reuse demand and service area.

Furthermore, equity of irrigation deliveries, including water quality, should be considered. Irrespective of the Basin water quality target of a maximum of 750 mg/L TDS, if one water user exclusively receives reused drainwater and another water user receives only river diversion water, a certain degree of inequity is perceived. Therefore, two criteria relating to water quality equity were established for this study: (a) all deliveries shall have a water quality less than or equal to 750 mg/L TDS, and (b) the maximum quantity of reused drainwater for any given field during the irrigation season shall not exceed 50 percent of the gross irrigation demand. The resulting maximum reuse factor was approximately 1 cfs continuous drainwater reuse per 100 acres. For example, a Basin drainwater reuse system with a capacity of 20 cfs should directly serve a minimum of 2,000 acres; the remainder of the irrigation demand should be supplied by surface water diversions.

Conveyance hydraulics were evaluated to determine which existing drainwater channels could be utilized for a new reuse system. The following conveyance factors were studied:

- Identifying drain reaches that can “backflow” by gravity depending on water levels
- Determining flow capacity
- Identifying drain reaches that require a pump station and pressurized pipe flow to re-enter the irrigation delivery system
- Identifying drain reaches that require regraded and/or reshaped channels
- Identifying the approximate typical cross section of regraded and reshaped channels required for the corresponding design flow
- Identifying existing infrastructure that needs to be modified or replaced

Hydraulic calculations were largely dependent on generalized engineering assumptions.

Results

A second stakeholder workshop was held to evaluate drainwater reuse alternatives. Two recommended alternatives resulted from the workshop. The first preferred alternative was selected for conveying 40 cfs of drainwater to the east of the main drain. This alternative was favorable for the following reasons:

- Operation of existing drainwater channels would be modified allowing drainwater to flow against natural topography toward the irrigation canal
- Drainwater would be pumped into the irrigation delivery system: there are multiple downstream laterals for irrigation deliveries
- The alternative features a comparatively short cross-connection between the main drain and the irrigation canal
- There is a reliable drainwater supply of sufficient quantity to sustain continuous reuse during the irrigation season
- Blending drainwater with a large quantity of surface diversion water results in a high degree of irrigation delivery equity

The second preferred alternative was selected for conveying 40 cfs of drainwater west of the main drain. This alternative was favorable because the drainwater would be blended with surface diversion water at the head of a distribution system. The supplemental irrigation source would alleviate water shortages and increase flexibility in the service area. Both of the preferred alternatives are mostly upstream of the area where salty connate water might cause a quality problem. Implementing both alternatives would provide up to 20,000 ac-ft of supplemental irrigation supply annually.

Drainwater quality concerns can be mitigated by (a) reusing drainwater upstream of the connate water zone, (b) blending drainwater with surface diversion water, and (c) implementing water quality monitoring program tailored to the recommended alternative. It is recommended that the monitoring program include an investigation of the long-term salinity build-up in the root zone.

DISCUSSION

Drainwater Reuse Challenges

Drainwater reuse comes with numerous challenges. While some challenges discussed below are specific to this Basin, many of them are common in some form with other drainwater reuse systems in other locations.

Identifying cost-effective drainwater conveyance is important. Drainwater often needs to be conveyed from the source to areas with adequate irrigation demand throughout the growing season. Elaborate new conveyance systems can become cost prohibitive; and oftentimes land is taken out of production. This study focused on using existing drainwater channels for conveyance to the extent possible. Both hydraulic control structures and operational strategies will be modified and a lift station will be installed to convey drainwater against natural topography so that it can be blended with surface diversion water. While the flat topography made this possible in this instance, the reader is encouraged to examine atypical conveyance strategies for similar drainwater reuse opportunities.

Controlling operation and maintenance cost is important to Basin farmers. The recommended drainwater reuse plan minimizes both the number of new pumps required and the lift head. This will keep energy consumption as low as possible. Regardless of the preferred alternative, a new drainwater reuse system will require ongoing flow rate, water level, and water quality measurements.

Maintaining equitable irrigation deliveries in terms of water quality must be accounted for when studying potential drainwater reuse systems. In this instance, blending drainwater with diversion water in irrigation canals will help keep water quality equitable, exceeding Basin standards for all. Additional drainwater reuse should be coupled with additional, ongoing water quality measurements to ensure the aforementioned equity.

Identifying a reliable drainwater supply was critical for delivering consistent and reliable reuse. Cropping pattern changes and shifts in cultural practices can presumably influence irrigation demand, drainwater flow magnitudes, and the timing of drainwater availability. Reliable drainwater sources were identified on RD 1500’s main drain, which collects surface drainwater from all drain laterals and offsets localized drainwater flow fluctuations.

Drainwater Reuse Benefits

Reusing drainwater can increase water delivery equity by reducing tailender problems, or alleviating water-shortage problems that are specific to certain service areas. In this case, reusing drainwater in the State Ranch Bend service area will allow the SMWC to deliver the volume of water needed to match peak irrigation needs.

Furthermore, drainwater reuse leaves available surface diversion water for use elsewhere. The benefit is especially critical and becomes more economically valuable when surface water allocations are reduced.

The benefits of increasing water delivery reliability through drainwater reuse should not be overlooked. With the recent increasing uncertainty of water supply because of drought and reduced allocations, the hard-to-quantify socioeconomic value of a reliable water supply has increased markedly. A reliable water supply goes beyond localized farmer profit; at some point it begins to influence food security. Expanding the Basin drainwater reuse system as supplemental irrigation supply will increase water delivery reliability.

CONCLUSION

Expediting the process of identifying drainwater reuse opportunities without extensive data was highlighted in this study. Stakeholder participation was a critical study component. Basin drainwater quality concerns can be mitigated by (a) reusing drainwater upstream of the high-in-TDS connate water zone, (b) blending drainwater with surface diversion water, and (c) implementing a specific water quality monitoring program in the final design.

Expanding the existing drainwater reuse system will help reduce diversion irrigation supply shortages while increasing irrigation delivery equity. There are potentially other means of improving Basin water use efficiency. This study was not intended to replace a comprehensive basin-wide master plan; in fact, such a plan is recommended to identify other ways to improve serviceability to Basin farmers. This will help categorize areas where water use efficiency can be increased; or highlight operational changes that can further improve the reliability of water sources, the flexibility of irrigation deliveries, and service equity. In the meantime, additional drainwater reuse of approximately 20,000 acre-feet annually can increase serviceability to Basin irrigators.

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AGREEMENT FOR MAINTENANCE AND REPLACEMENT OF "CONDUIT" CROSSINGS WITHIN COUNTY RIGHTS-OF-WAY

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ABSTRACT

Irrigation districts and other public agencies in California are often challenged when facility replacement and maintenance occurs within County rights of ways. Many districts operate under verbal agreements with counties, and when written agreements do exist, the terms of the agreements are not necessarily followed.

In the case of Oakdale Irrigation District (OID), a Conduit Maintenance and Replacement Agreement (Agreement) was entered into with Stanislaus County in the 1980s when OID implemented major system improvements under a Bureau of Reclamation financed distribution system improvement program. Following completion of those improvements the agreement was essentially ignored resulting in system maintenance modifications that do not necessarily conform to the Agreement.

In 2007, OID completed its Water Resources Plan (WRP), which maps out a new, comprehensive program of system modernization improvements that define OID's major capital improvements for the next 25 years. Given the magnitude of the planned improvements, it became clear that OID needed to revisit its Agreement with Stanislaus County.

This paper discusses OID objectives in seeking an updated Conduit Maintenance and Replacement Agreement with Stanislaus County (County). The legal basis for the Agreement under the California Water Code is briefly reviewed and the renewed Agreement is critiqued. Suggestions are offered for provisions that should be addressed in similar agreements pertaining to rights of way shared between local public agencies.

INTRODUCTION AND BACKGROUND

<u>History and General Summary</u>

Oakdale Irrigation District (OID) is located in the northeast portion of the San Joaquin Valley, approximately 30 miles southeast of Stockton and 12 miles northeast of Modesto in both San Joaquin County and Stanislaus County. OID was organized in 1909 under the California Irrigation District Act by a majority of landowners in order to legally acquire and construct irrigation conveyance facilities for the distribution of irrigation water from the Stanislaus River. In 1910, OID and the neighboring South San Joaquin Irrigation District (SSJID) purchased Stanislaus River water rights and some existing conveyance facilities from previous water companies. Over the course of the next several decades,

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OID continued to expand its conveyance facilities. In general, OID's facilities, system operations, political organization and administration have not changed significantly since its creation in 1909. Nearly all conveyance facilities were constructed 50 years ago or more. OID currently maintains over 330 miles of open channels, pipelines and tunnels, 29 production wells and 43 reclamation pumps to serve local constituents. OID currently serves 2,800 agricultural customers encompassing approximately 57,000 acres of irrigable land. Design flowrates range from approximately 400 cubic feet per second (cfs) in the main canals to approximately 10 cfs at the end of the conveyance system. OID also provides domestic water to approximately 700 constituents primarily located east of the City of Oakdale.

Agriculture is the dominant land use in and surrounding OID, with pasture making up approximately half of OID's irrigated area, or about 32,000 acres. The other half consists of orchards, corn and oats (typically double cropped), and urban land, in relatively equal fractions. In recent years, however, OID's customers, land use and financial resources have developed in a direction that has influenced the way OID provides service and conducts business.

Water Resources Plan

In 2004, OID initiated development of a Water Resources Plan (WRP), setting forth an operational strategy for the next 25 years. The WRP is a tool to help OID achieve its goals of providing long-term protection of water rights; addressing federal, state and local water challenges; rebuilding/modernizing its outdated system to meet changing customer needs; developing affordable ways to finance improvements; and involving the public in the planning process. The WRP was comprised of 4 phases: (I) Perform detailed assessment and data collection; (II) Prepare programmatic CEQA document and finalize the WRP; (III) Develop Implementation Plan and (IV) Implement WRP (Engineering, Design and Construction).

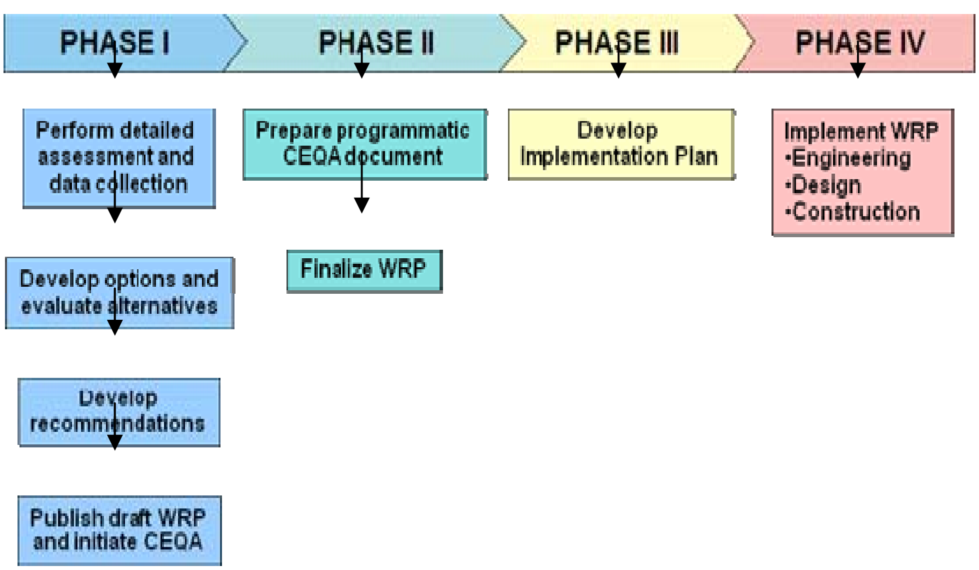

Figure 1. The Four Phases of the OID Water Resources Plan

In 2007, OID completed the WRP and is now proceeding with Phase IV implementation at an estimated cost of $169 million (2005 dollars). Major implementation components include lateral rehabilitation, improved flow control and measurement, installation of new ground water wells, facilities mapping, upgraded aquatic pesticide program, pipeline replacement, construction of a new north side reservoir, turnout replacement, outflow management projects, reclamation projects and main canal and tunnel improvement projects. Based on annual cost escalation of 3.5%, current costs are estimated to be around $190 million today.

<u>Existing Conduit Crossings</u>

OID has approximately 225 lateral conduit crossings (and additional drainage crossings) within the County. As noted above, many of these facilities were built 50 years ago or more and have reached the end of their designed lives. While several conduit crossings have been replaced since their original construction, Figures 2 and 3 shown herein are indicative of the condition of most existing conduit crossings within the County.

Figure 2. OID North Main Canal Conduit Crossing at Sonora Road

Figure 3. OID Brichetto Lateral Conduit Crossing at Oakdale Waterford Highway

Conduit crossings like the ones shown above are being replaced for a variety of reasons including proximity to the traveled path (motorist safety), safety concerns for OID Water Operations Staff associated with routine maintenance during the irrigation season, entrance conditions and existing structural integrity. These conduit crossings will be replaced as part of the Capital Improvement Plan set-forth in the WRP on an as-needed basis to be determined by either failure and/or replacement due to existing flow constraints. Replacement will occur gradually as part of overall system rehabilitation as monies become available.

<u>Purpose and Scope of Agreement</u>

Given the magnitude of the planned improvements as highlighted above, it has become clear that OID needs to review and update its existing Conduit Maintenance and Replacement Agreement (Agreement) with Stanislaus County. While OID lies within both San Joaquin County and Stanislaus County, an agreement was first drafted with Stanislaus County because it contains the majority of the OID service area. The existing Agreement with the County was executed in July of 1985 at the request of the County in anticipation of work to be performed as part of a distribution system improvement project financed through the Bureau of Reclamation under the provisions PL-984 loan program.

REVIEW AND ASSESSMENT OF EXISTING AGREEMENT

The existing Agreement is comprised of the following eight provisions (please note that these conditions appear below in exactly the same format that they appear in the existing Agreement):

1. County to furnish all signs and barricades.

2. County to furnish aggregate base material or other appropriate backfill for deep pipes at the site of the work.

3. Irrigation District to install pipe and backfill to surface of road.

4. County to repave road.

5. County/Irrigation District to share cost of pipe 50/50.

6. County to be responsible for all work performed by same.

7. Irrigation District to be responsible for all work performed by same.

8. Cost share of pipe replacements is based entirely on only those pipes which are leaking and causing a potential liability problem and/or damaging the County Road. If they meet the above criteria, then whether they are replaced under your PL-984 project or not would have no bearing on our participation. We would not participate on any pipeline replacement which is merely an upgrading of your facilities. Legally we are not able to use gas tax funds for such work.

These provisions address the construction or improvement of conduit crossings and were intended to assign tasks associated with the replacement to that agency best suited to perform those functions, but they do not address the key issues of facility ownership, operation and maintenance, as provided for under the California Water Code. The objectives in updating the Agreement are to ensure that it is consistent with the California Water Code, comprehensive in scope, amenable to both OID and the County, and legally defensible.

PERTINANT CALIFORNIA WATER CODE PROVISIONS

Division 4, Section 3 of the California Water Code (2009) contains certain provisions pertaining to irrigation facilities. Three provisions are pertinent to the updated Agreement:

A “conduit” is defined to include a canal, ditch, culvert, pipeline, flume, or other appliance for conducting water.

Section 7034, entitled, "Bridges maintained by county or state", states the following:

- Bridges or conduits heretofore or hereafter constructed in a permanent manner, whether by encroachment permit or otherwise, which cross county highways and which have been constructed or brought up to county standards, and have been accepted, either formally or informally by appropriate action, shall, after such acceptance, and regardless of who constructed them, be the sole responsibility of the county, so far as maintenance, repair, improvement for the benefit of the county, reconstruction or replacement of such bridges and conduits are concerned. If any such county highways become state highways, the State shall succeed to the foregoing obligations of the county.

Section 7035, entitled, "Conduit crossing highway; presumption; repair, improvement or replacement", states the following:

- Whenever any conduit for conducting water crosses a highway and no written record exists showing that the highway rights-of-way existed prior to the conduit rights-of-way, it shall be conclusively presumed that the conduit was in place and lawfully maintained prior to the highway and such conduit shall be repaired, improved for the benefit of the public agency having jurisdiction over such highway, and replaced, if necessary, by the public agency having jurisdiction over such highway, provided that usual acts of maintenance of the conduit, such as cleaning the conduit of dirt or silt, shall be performed by and at the expense of the person using the conduit.

Section 7036, entitled, "Costs of locating, removing, repairing, relocating facilities on roads or other property", states the following:

- Any public district or private utility and any county may enter into a contract agreeing to pay and apportion between them the costs of locating, removing, repairing, or relocating any facilities owned or to be owned by either party on the roads or other property of the other in such proportion and upon such terms as the governing boards of the parties shall determine to be equitable.

While the new Agreement will contain numerous conditions as shown below, these three sections from the California Water Code will be the legal basis for the new Agreement with the County and clearly define, ownership, maintenance responsibility and replacement responsibility.

PROPOSED PROVISIONS OF THE UPDATED AGREEMENT

OID has been in ongoing negotiations with the County for nearly two (2) years now and OID intends to finalize the Agreement with the County in 2009. The provisions outlined below have been identified by OID as those conditions deemed necessary for the Agreement, recognizing that final conditions will be shaped by negotiation between the parties.

Reference to California Water Code: Reference to the above noted applicable sections of the California Water Code should be made in the beginning of the Agreement as the basis for the Agreement.

Encroachment Permits: Encroachment Permits are commonly required by agencies as a means of granting permission for encroachments within easements, rights-of-way or fee titled lands and often times there is a cost associated with obtaining said permit. It is important to note in this application that the conduit is owned by the agency having jurisdiction over the road as set-forth in the California Water Code and as such there is no need for an Encroachment Permit.

Maintenance: It was determined that all facility maintenance of conduit crossing would be the responsibility of the County. OID recognizes that during the irrigation season its employees will still clean debris from the upstream side of road crossings and take whatever means necessary to ensure the continued delivery of irrigation water resulting in OID being responsible for operational maintenance.

Replacement Cost: OID and County agreed to a 50/50 cost share of the total project cost, subject to budget authority by both parties for only those conduits in which their replacement was determined mutually beneficial. The total project cost shall include, but not be limited to costs associated with engineering, surveying, labor and materials, storm water bypass, fencing, inspection, soils/material testing, traffic control and contract management. OID and County agreed to bear 100% of the total project costs for those conduit replacement projects deemed necessary for the sole benefit of either OID or County.

Design Parameters: For the purposes of this Agreement, OID and the County agreed that all conduit replacement projects shall be designed to accommodate the “maximum potential flow rate” or that flow rate determined practical by both OID and County. The “maximum potential flow rate” shall be determined by the greater of the following; (1) the maximum irrigation design flowrate, (2) the maximum irrigation drain water flow rate or (3) the maximum storm water flow rate as calculated in accordance with Chapter 4: County Storm Drainage Standards. While OID is technically not responsible for the potential added costs associated with upsizing the conduit to handle condition 3, these costs are thought to be minimal in comparison to total project cost.

Drawing/Calculation Review: It is important that both Engineering Departments review the necessary design calculations and design drawings prior to bidding the project and ultimately the start of construction. Too often this does not happen and more often than not results in costly change orders.

Construction Timing: OID’s construction season is generally defined as commencing on or about October 15th and concluding on or about March 15th. It is often the Counties desire to perform road improvement projects during the irrigation season (March 15th to October 15th) and it should be noted that the uninterrupted conveyance of irrigation/drain water during construction is necessary and County shall provide for and pay 100% of the costs associated with temporary bypass of irrigation/drain water conveyance around the project site during the irrigation season.

Limits of Agreement: It should be noted that the terms of the Agreement are only applicable to those conduits utilized by OID and shall not include those conduits utilized for conveyance of private irrigation water or private drain water or those conduits utilized for the sole benefit of County.

CONCLUSION

This Agreement along with various other Agreements of this nature are thought to be extremely valuable to local public agencies in providing a legal basis for their actions while providing a clear and concise guideline for the project from design through construction. This Agreement is undoubtedly a dynamic document and as more and more conduit replacement projects are completed it will change accordingly.

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METHOD FOR IRRIGATION SCHEDULING BASED ON SOIL MOISTURE DATA ACQUISITION

B. K. Bellingham[1]

ABSTRACT

The water requirements of crops are dependent on evapotranspiration (ET), soil chemistry, and the crop's maximum allowable depletion (MAD). Direct measurements of root zone soil moisture, water application along with published ET values and soil textures, can be used in a soil water balance model that can significantly optimize irrigation efficiency. Over the past five years, advancements in computer microprocessors, memory, and software development tools has improved data acquisition methods and made data acquisition system integration more reliable and more cost effective. We discuss here an irrigation scheduling method based on a volumetric soil moisture balance model and data acquisition.

INTRODUCTION

In the western United States, irrigation accounts for about 80% of the water consumed. (Hutson 2000). Concerns about changes in land use due to growing populations, climate change, and the protection of aquatic habitats are driving a need to conserve water. Optimization of irrigation will not only benefit the environment, but also benefit local economies.

Over irrigation may lead to dangerous increases in the total maximum daily loads (TMDL) of temperature, nitrates, and salinity in natural waters (Chapman 1992). Nitrate fertilizers leached out of the soils get transported to natural waters causing eutrophication and other aquatic impairments. Run off from over irrigation may affect water quality parameters such as pH, total suspended solids (TSS), and dissolved oxygen (Winter 2002). Other negative impacts associated with over irrigation include wastes of water and energy, and reduced crop yields.

The negative impacts associated with under irrigation are more intuitive. Under irrigation may reduce crop yields, which will reduce profit margins.

A soil water balance model incorporated into a data acquisition system is a power tool for scheduling and optimizing irrigation. Advancements in computer microprocessors, memory and software development tools has improved data acquisition methods and made data acquisition system integration more reliable and more cost effective.

The soil water balance model incorporates inputs of soil moisture, water application and evapotranspiration (ET). The soil moisture data acquisition system retrieves the input

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parameters via telemetry and populates software that accommodates the soil water balance model. The soil data acquisition software integrated with a soil water balance model is commercially available from Stevens Water Monitoring Systems, Inc.

SOIL MOISTURE BUDGET

To begin our discussion about soil moisture budgets, we first describe the components and the hydrological conditions of soil. In general, inorganic soil is composed of mixes of sands, silts and clays. Sands, silts and clays differ not only by particle size distribution, but also in the atomic arrangement and charge distribution at the molecular level (McBride 1994). Soil geomorphology is the process by which sands and silts chemically and physically transform into clays as the soil ages (Birkeland 1999).

The soil textural class is determined by the gravimetric percentage of sand silt and clay. Figure 1 shows the soil texture classifications based on gravimetric percentage.

Figure 1. Soil textural classes based on the percentage of sand, silt, and clay.

Sands, silts, clays, and organics represent the solid particle composition of soil while air and water fill the pore spaces between the solid particles. When soil is completely saturated with water, the porosity will be equal to the volumetric soil moisture content (Warrick 2003). The amount of organics in soil will affect the bulk density and the porosity. Some organic soils may have porosities of over 90%, but in general, most inorganic agricultural loams will have a porosity of near 50%. The pores can be nearly microscopic (micro-pores) or visible with the naked eye (macro-pores) (Brady 1974)

The hydrologic properties of soil play an important role in a crop's ability to transpire water with their root systems. Knowledge of volumetric soil moisture content (θ, $m^3\ m^{-3}$)

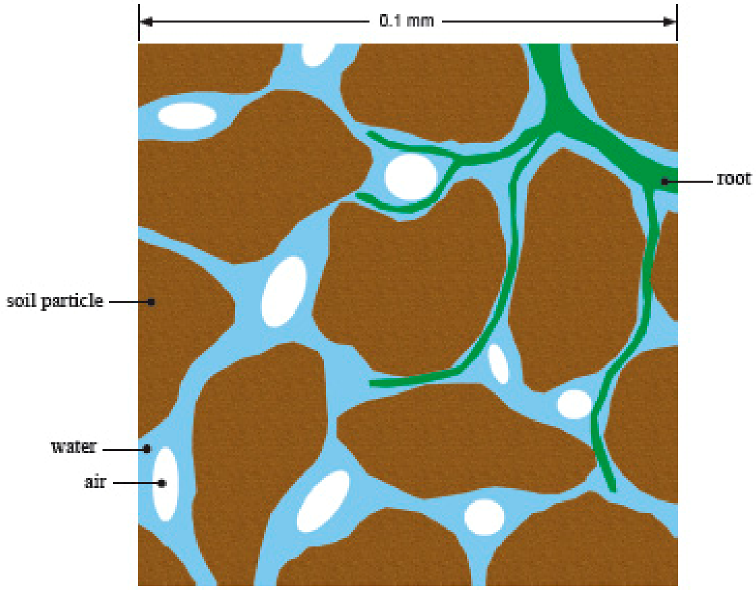

Figure 2. Unsaturated soil is composed of solid particles, organic material and pores. The pore space will contain air and water.

is an important input into the soil water balance model. Permanent wilting point (θ_{PW}) is the soil moisture level at which plants can no longer adsorb water from the soil. Plant transpiration and direct evaporation will decrease the moisture level in soil to a point below θ_{PW} and, in some cases, down to near dryness.

Field capacity (θ_{FC}) is defined as the threshold point at which the soil pore water will be influenced by gravity. Above field capacity, the gravitational force will overcome the capillary forces suspending the moisture in the pores of the soil allowing for down movement of water in the soil column. Below θ_{FC} , there will be a net upward movement of water driven by ET. Soil textural classes heavily influence field capacity and permanent wilting point, particularly clay content (Rowell 1994). Clays interact with water in ways uniquely different from sand, silt and organics. Clays will have a physical and chemical affinity for water due to the negative charge distribution and the planner molecular lattice. The positive portion of the water molecule will be oriented toward the negatively charged clay lattice and the oxygen's lone electron pair will be pointed outwards (Grim).

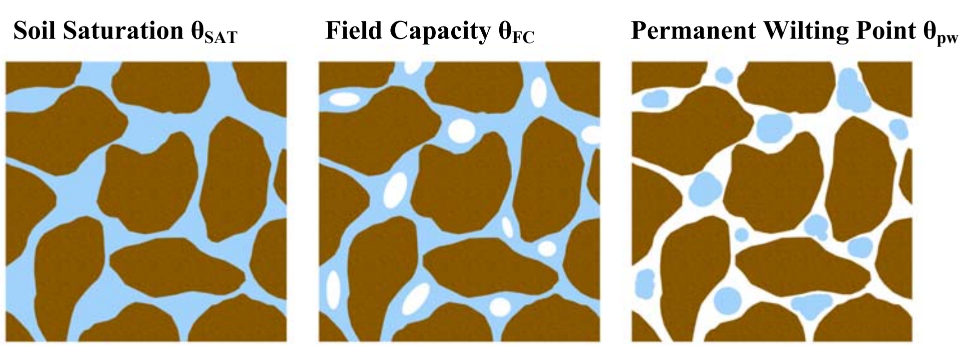

Figure 3. Soil saturation, field capacity and permanent wilting point.

Positively charged cations will also be influenced by the negative charged distribution of clay (McBride1994). Figure 3 shows two cations of different valance states (Ca^{++} and Na^{+}) chemically influenced by clay at the molecular level. Figure 3 also shows the charge distribution of the water molecule.

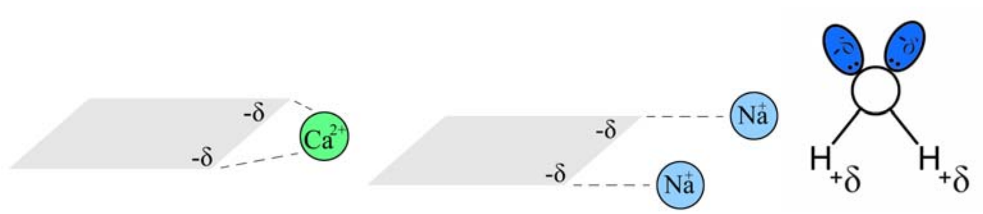

Figure 4. Planner clay lattice with a negative charge distribution and cation influence. Dipole moment of a water molecule.

The available water capacity (θ_{AC}) of soil is the water that is available to a plant. It represents the range of soil moisture values that lie above permanent wilting point and below the field capacity.

$$\theta_{PW} < \theta_{ac} < \theta_{FC} \quad [1]$$

Table 1 shows the typical values for permanent wilting point and field capacity for common soil textural classes (Rowell 1995).

Plants are able to uptake water from soil if the soil moisture is above permanent wilting point. As the soil moisture approaches permanent wilting point, the plant will become increasingly stressed as the soil pore water becomes depleted. The point below field capacity where plants become stressed is called the maximum allowable depletion (MAD). The MAD value is expressed as a percent of the available water capacity. Table 2 shows typical MAD values for a few selected crops.

Table 1. Field Capacity and Permanent wilting points for common soil textural classes

	Field Capacity	Permanent Wilting Point
Sand	0.12	0.04
Loamy Sand	0.14	0.06
Sandy Loam	0.23	0.1
Loam	0.26	0.12
Silt Loam	0.3	0.15
Silt	0.32	0.165
Sandy Clay Loam	0.33	0.175
Silty Clay Loam	0.34	0.19
SiltyClay	0.36	0.21
Clay	0.36	0.21

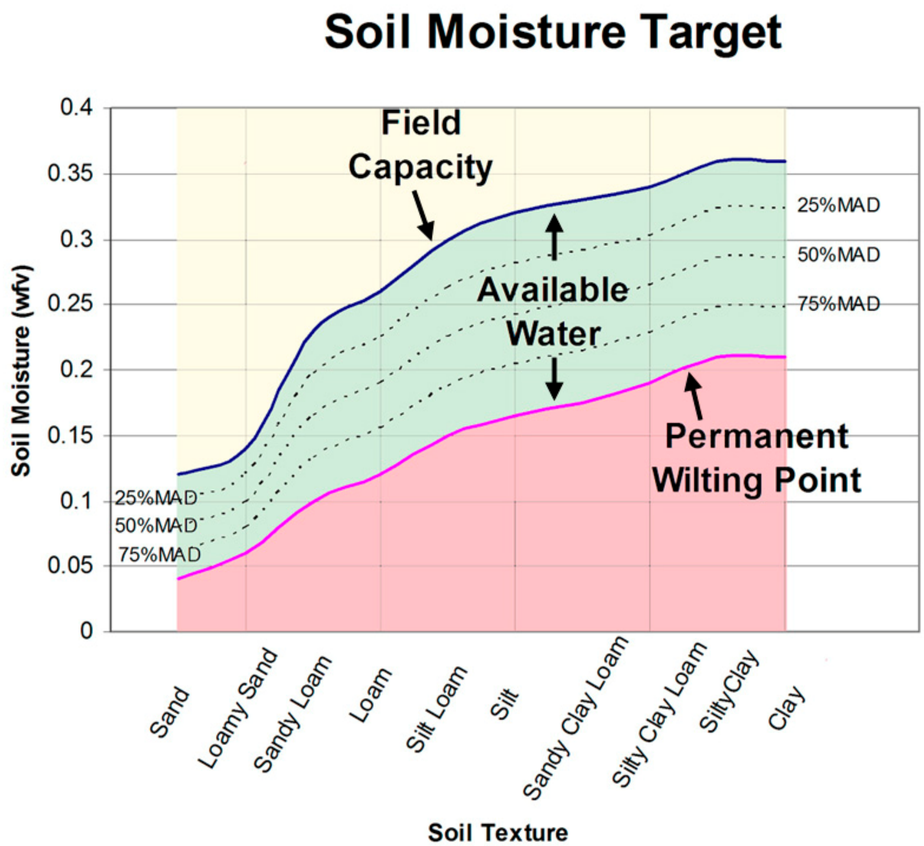

Figure 5. The relationship between soil textural classes and the hydrological thresholds θ_{PW} , θ_{AC} , θ_{FC} . The 25%, 50% and 75% MAD levels are displayed in the available water capacity region.

Table 2. Maximum Allowable Depletion based on crop. Effective Root Zone Depth. Taken from Smesrud 1998.

Crop	Maximum Allowable Depletion (MAD)	Effective Root Depth (Inches)
Grass	50%	7
Table beet	50%	18
Sweet Corn	50%	24
Strawberry	50%	12
Winter Squash	60%	36
Peppermint	35%	24
Potatoes	35%	35
Orchard Apples	75%	36
Leafy Green	40%	18
Cucumber	50%	24
Green Beans	50%	18
Cauliflower	40%	18
Carrot	50%	18
Blue Berries	50%	18

Figure 4 shows the soil field capacities and the permanent wilting points for common soil textural classes. The green region in figure 4 is the available water capacity showing 25%, 50% and 75% MADs. As shown in figure 4, the field capacity and the permanent wilting point will increase with the percentage of clay.

With specific knowledge of field capacity, soil textural class and the maximum allowable depletion, a soil moisture target can be determined for irrigation optimization (Brouwer 1985). The soil moisture target is the range of soil moistures that lie above the MAD but below the field capacity. Below the MAD value the crop will still have the ability to receive water from the soil, however the crop will become stressed after a period of time. If the crop becomes stressed due to the lack of water, the plant will have a reduced yield and become more susceptible to pathogens. If the soil moisture gets above field capacity, water will be transported downward by gravity potential wasting water and leaching nutrients.

Upper soil moisture target for the soils in the root zone will be the field capacity. The lower soil moisture target is determined by the MAD, θ_{FC}, and θ_{PW};

$$\text{Lower Soil Moisture Target} = \theta_{FC} - (\theta_{FC} - \theta_{PW}) \text{ X MAD} \qquad [2]$$

For example, green beans with a MAD of 50% have a root zone depth of 18 inches. If the green beans are growing in a silt loam, the field capacity will be 0.3 water fraction by volume (wfv) and the permanent wilting point will be 0.15 wfv. Using equation [2], the lower soil moisture target will be 0.23 wfv. In this example, the soil moisture target for the green beans will lie between 0.23 wfv and 0.3 wfv from 5 inches to 18 inches deep adjacent to the root ball. It is important to note that the values in table 1 are typical values and could vary slightly with bulk density of soil, mineralogy and organic content. Similarly, the MAD values in table 2 are typical values and may vary by species, age of crop, region and soil chemistry.

WATER APPLICATION

While soil moisture data provides information about the root zone, the measured application of water can be used concurrently with the soil moisture values to provide a more complete suite of tools for the irrigator. The measured application of water (*D*) is the amount of water applied to the crops with sprinklers, plus the amount of natural precipitation measured in inches/day. It is the total depth of water received by the crop.

Sprinkler Efficiency

In order to effectively use the application of water in a water budget model, a high sprinkler efficiency (E_f) is required. Sprinkler efficiency (E_f) is the measure of uniformity of water application. Ponding of irrigation water, and uneven application of water over the field is the result of poor sprinkler efficiency. Soil moisture data and rain gauge data are less meaningful if the monitoring site receives more or less water than the rest of the irrigation regime. Sprinkler efficiency is determined by placing catch cans or a set of uniform containers in the field. The catch cans can be placed in grid or uniformly distributed amongst the crops. After running the sprinklers for a length of time, the amount of water in the catch cans is measured. The sprinkler efficiency is expressed as a fraction and an E_f value of 1 is perfect uniformity. There are a number of methods for calculating E_f. The most common method for determining E_f involves averaging the lower 25% of the measured catchment of catch cans divided by the mean. An E_f value greater than 0.8 is preferred. Table 3 shows typical E_f values for several different types of sprinkler systems.

Table 3. Typical values for sprinkler efficiencies for various sprinkler systems. Taken from Smesrud 1998.

Irrigation System	Sprinkler Efficiency (E_f)	Sprinkler Efficiency (sprinkler spacing over 40 X40 feet)
Solid Set	0.70	0.63
Hand Move or Side Roll	0.80	0.74
Pivot or Linear Move	0.90	0.81
Offset Managed Hand Move	0.90	0.81

Evapotranspiration

An important factor for quantifying the water budget is the evapotranspiration rate (*ET*). Evapotranspiration is the water that is transpired out of the soil by the plant plus the amount of water lost to evaporation (Allan 1998). *ET* represents the rate of water consumed by the plant and lost by direct evaporation. The factors that affect the *ET* rate include wind, temperature, relative humidity, and solar radiation. The units for *ET* are inches/day.

Based on the Penman Monteith model for *ET* estimations, *ET* is not measured directly for an individual crop, but rather it is determined from a standard reference grass and then adjusted for different crops and plants with a crop coefficient (Allen 1998). The evapotranspiration for a reference grass is referred to as the potential evapotranspiration (ET^0). Potential evapotranspiration values will vary regionally and seasonally and are available in the literature. If literature values for ET^0 are not available or if the irrigator wishes to have a real time ET measurements, ET data acquisition systems are commercially available. ET data acquisition systems consist of weather sensors, telemetry and software that can retrieve the weather sensor inputs and perform the Penman Monteith model calculations. While an ET data acquisition system could potentially provide accurate real time ET^0 values, theses systems are very expensive and do not necessarily represent microclimates.

Because ET^0 is the *ET* for a standard reference grass, a crop coefficient (K_c) is necessary to determine the *ET* for the crop of interest. With information about sprinkler efficiency, crop coefficient and potential evapotranspiration, the water consumption (*ET")* for a specific crop (in inches per day) are calculated from the equation [3],

$$ET'' = ET^0 \times K_c / E_f \qquad [3]$$

Typically, K_c values will range from 0.75 to 1.25 depending on species of the plant, the growth stage of the plant, and vary regionally. In practice, ET^0 and K_c values can be obtained from a local government crop extension or a local crop advisor.

Applied water Scheduling

In general, the water application (D) in inches/day should be roughly equal to the system water loss (ET'') due to ET and sprinkler uniformity. The water loss calculated by equation [3] can be compared to the applied water measured with a rain gauge to set an irrigation target.

$$D \approx ET'' \qquad [4]$$

If is difficult to keep $D \approx ET''$ on a hourly or daily basis due to factors such as pivot lap speed and soil infiltration rates. Equation [4] should define a water application target on a weekly basis. In general, depending on the crop and the irrigation system, crops should be irrigated 3 to 7 times a week and net weekly sum of the daily D values should be roughly equal to the net weekly sum of the daily ET'' values. Figure 5 demonstrates a weekly water application target. In figure 5, there are three irrigation events, and an ET'' rate of 0.26 inches per day. Based on an ET'' rate of 0.26 inches per day and the E_f, by the end of the week, 1.80 inches of water was consumed and approximately 1.80 inches would need to be applied.

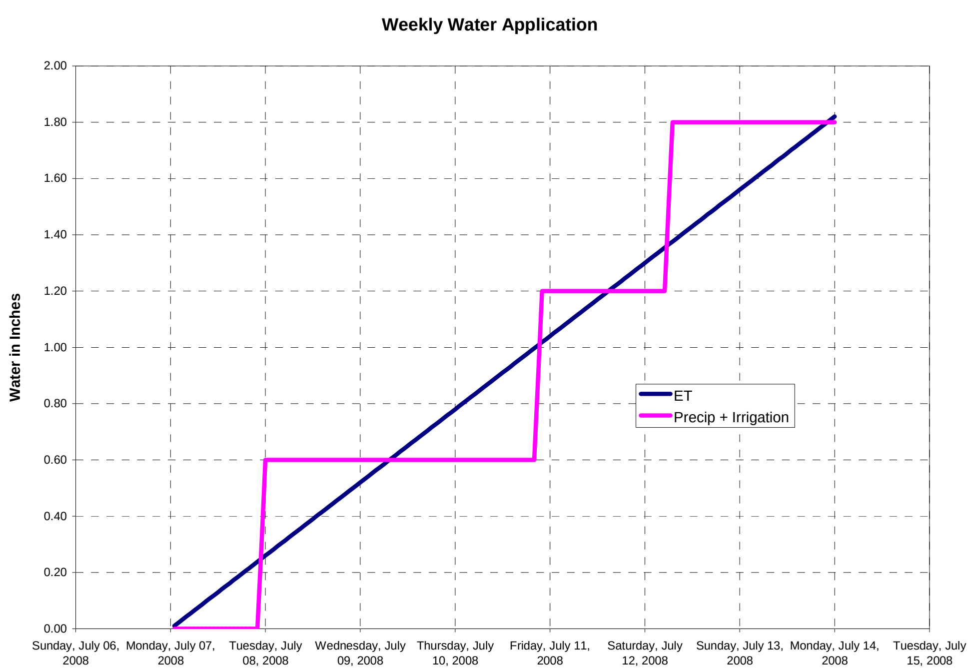

Figure 6. There are three irrigation events, and an ET'' rate of 0.26 inches per day. $D \approx ET''$ after the 3 irrigation event at the end of the week.

The application rate in figure 5 is 0.3 inches per hour for 2 hours. To minimize the water loss due to direct evaporation, the irrigation events take place between sunset and sunrise.

It is important to irrigate at a rate that is less than the infiltration rate of the soil. Runoff and ponding may occur if the rate of application exceeds infiltration rate of the soil. Table 4 provides infiltration rates of soils based on soil textural class (Brouwer 1988).

Table 4. Typical Infiltration rates based on soil texture.

Soil Texture	Typical Infiltration Rate (inches/hour)
Sand	1.5 or more
Sandy Loam	1 to 1.5
Loam	0.5 to 1
Clay Loam	0.25 to 0.5
Clay	0.05 to 0.25

The infiltration of water into soil will vary with texture, but it will also depend on soil moisture, vegetation, bulk density and soil goemorphology among other factors. Soil infiltration rates can be determined from tests and area soil surveys data.

DATA ACQUISITION

Data acquisition systems are the most effective tool for identifying and reaching soil moisture and water application targets for irrigation optimization. A data acquisition system with the water budgeting method was constructed and is commercially available from Stevens Water Monitoring Systems, Inc.. The Stevens Agricultural Monitoring (SAM) Package integrates the input from sensors, displays the data from the remote field locations and integrates the water balance method described in the previous section. The SAM package includes rain gauges, the Stevens Hydra Probe Soil Sensor, a Stevens DL3000 data logger, telemetry and the software program. Described below is the engineering that collects field data (soil moisture and precipitation) and the software program that acquires the data from the data loggers through the telemetry. The data is either exported to the internet or is imported into the SAM software where it can be used to make informed decisions about irrigation scheduling.

Soil Moisture Data Collection

The soil moisture is collected using the Stevens Hydra Probe. The Hydra Probe is the soil sensor used in the USDA's Soil Climate Analysis Network (SCAN) and NOAA's Climate Reference Network (CRN). The Hydra Probe uses electromagnetic waves to measure both the real and imaginary dielectric permittivity (Campbell 1990). The real component of the dielectric permittivity represents the energy storage based on the high rotational dipole moment of water compared to that of dry soil (Topp 1980). The measured real dielectric permittivity (ε_r) is used to accurately calculate the soil moisture in water fraction by volume in most soils (Seyfried 2005) with the calibration equation;

$$\theta = A\varepsilon_r^{1/2} + B \qquad [5]$$

Where A is 0.109 and B is equal to -0.179. The Hydra Probe is digital and equation [5] is written into the firmware of the probe.

The digital communication between the Hydra Probe and the data logger is the standard communication format Serial Data Interface at 1200 Baud (SDI-12). The advantages of SDI-12 include connecting many sensors on a single serial addressable bus and cable lengths up to 1000 feet from the sensor to the data logger. Multiple digital sensors are "daisy chained" together and the longer cable lengths provide flexibility in the architecture of the system in the field. Up to 4 or more SDI-12 soil moisture profiles can be installed up to 1000 feet away from the data logger reducing the cost by using common data loggers and telemetry.

Rain Data Collection

The precipitation and the irrigation from sprinklers are measured together with a tipping bucket rain gauge. A tipping bucket is a 6 to 10 inch in diameter cylinder with a screen at the top facing end and a drain out the bottom. Inside of the bucket is a dual sided tray that is located under a funnel. The tray will tip over and drain after receiving 0.01 inches of rain. After tipping, the other half of the tray will fill with water, tip and drain after receiving another 0.01 inches of water. Every time the tipping bucket's tray tips (0.01 inch of rain), an electrical pulse is sent to the DL3000 data logger. The data logger counts the tips and calculates the depth of rain fall over time. It is important that the tipping bucket remain level and is placed in a location that will receive a representative application of water from the sprinklers.

If an irrigation method is used that does not include the use of sprinklers such as furrow or drip irrigation, the method described in figure 5 and equation [4] will not be as applicable. In this case, one or no rain gauge would be used in the data acquisition package.

Data Logger and Field Station

The Stevens Data Logic 3000 (DL3000) data collection platform resides inside a weather proof fiber glass enclosure located in the field. The cable from each SDI-12 Hydra Probe enters the enclosure by running through bulkhead bushings located on the bottom of the enclosure. The Hydra Probe power, ground and SDI-12 communication wires are "daisy chained" together with a multiplex inside the enclosure. A single SDI-12 communication wire runs from the multiplexer to the DL3000's SDI-12 communication port. The DL3000 will log data on a set time interval typically every 30 minutes, and will hold up to 2 Gigabytes of data. The wire from the tipping bucket also runs into the enclosure through a bulkhead and is wired into the DL3000's pulse port. The data logger has a wireless RS232 communication radio attached. A coaxial cable runs from the radio out of the enclosure through the bulkhead to an Omni directional antenna.

Also contained in the field enclosure is a 9 Amp/hour 12 volt DC battery, and charge regulator for the solar panel power supply. Figure 9 describes a field station with a subsurface soil moisture monitoring profile.

Wireless Telemetry

After the data from the sensors is received by the data logger, the data is transmitted from the field to the base station computer via radio. The frequency and type of radio would depend on the distance from the field to the base station computer. The radio communication between the field and the base station is usually line of sight. Large obstacles such as buildings, mountains and trees will impede the radio signal and prevent the signal from reaching its destination. If there is a large obstacle in the way, a repeater station could be installed, however repeater stations will increase the overall cost of the system. Radio communication always takes place between two or more radios. The radio at the base station is called the server or master radio and the radios in the field are call client or slave radios.

The master radio is connected to the base station computer and a directional Omni antenna. Each radio has a Media Access Control (MAC) address written into the radio's firmware, identifying it. When the master radio needs communication with a specific radio, the master radio will address the radio with the MAC address. Radios will only respond their specific MAC address from the master radio. In a network of radios, the master radio will communicate with each slave radio one by one and retrieve the sensor data from each logger individually.

Distance from the field site to the base station is the main factor determining the most appropriate radio and frequency. In most agriculture applications, 900 MHz Spread Spectrum radio with a 5 miles line of sight range is the most common. While satellite communication is common in the water resources industry, it is less common at the farm level due to licensing and hardware costs. Table 5 lists the different kinds of telemetry solutions, the ranges and the frequencies.

Table 5. Summery of telemetry options and ranges.

Radio	Range	Frequency
Blue Tooth	100 m	2,400 to 2,483.5 MHz
Spread Spectrum	5 miles	902 to 928 MHz
Wi-Fi	100 m	2.4 GHz
VHF	30 miles	30 to 300 MHz
UHF	30 miles	300 to 1,000 MHz
Wi-Max	30 miles	2.3 to 3.5 GHz
Cellular Modem	Cell Coverage	824.01 to 848.97 MHz
Geosynchronous Satellite	1/3 the of Earth	401.7010 to 402.0985 MHz
Low Earth Orbiting Satellite	Global Coverage	148 to 150.05 MHz

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Soil Profile

Soil moisture probes at different depths in the soil column are referred to as a soil profile. Depending on the root zone depth, the typical soil profile consists of four soil sensors. One probe in the top soil (2 to 4 inches) two probes in the root zone (6 to 30 inches) and one probe below the root zone (36 inches). The Hydra Probe in the top soil will experience the greatest moisture fluctuation because it will be the most influenced by ET and downward flow. The top soil may reach saturation or reach a soil moisture value over the field capacity thus conducting water downward into the root zone of the crop. The lower soil moisture target for the two Hydra Probes in the root zone however are calculated from the MAD, θ_{FC} and θ_{PW} in equation [2] and the upper soil moisture target in the root zone will be the soil's field capacity. The soil sensor below the root zone should stay below field capacity. If the soil moisture below the root zone reaches values above field capacity, there will be downward conductance of water.

The soil profile should be placed in a location that will most represent the irrigated area. Soil moisture can be highly variable spatially (Western 2003). The factors that affect soil moisture variability are slope, vegetation type, bulk density, soil type, microclimate, and other variables. An irrigation regime represents an area that is homogenous enough that the soil moisture variability will be low and the soil moisture data will represent the entire irrigation regime. There should be at least one soil profile for every irrigation regime. Irrigation regimes are determined by crop type, crop age, soil type, slope, and irrigation method.

If the irrigation regimes are less than 1000 feet apart, it may reduce cost to tie multiple soil profiles into one data logger. By tying multiple profiles into a single data logger, the irrigator can save on the number of solar panels, batteries, radios, data loggers and other necessary accessories.

Data Acquisition Software

The central user interface of the data acquisition package is the software.
The Stevens Agricultural Monitoring (SAM) Software is commercial available and can be subsidized by some energy and water conservation grants. The SAM software runs on a computer that is connected to the master radio. A master radio is not necessary if the system has a field cellular modem or satellite transceiver. The SAM Software acquires the sensor data in the field from a polling sequence. The polling sequence runs at a user specified time interval, which is usually every 15 or 30 minutes. Communication begins with a serial command from the software to the data logger to take a current a current reading from all of the sensors. The SAM sends the command to the master with instructions to use a specific slave radio. The data logger becomes active after receiving the command and takes a current reading from all of the sensors that are connected to it. Next the data logger sends a comma delimitated string of sensor data back to the SAM software through the slave and master radio. The SAM software parses the data and populates the tables and graphical displays in the software.

The irrigator can then view the real time data and make decisions about when to irrigate based on the soil moisture targets and the rate of water consumption by the crop from the ET. Other features in the software include battery voltages for power management. In the SAM Software, a display of MAD, θ_{FC}, θ_{PW} and the lower soil moisture limit based on the calculations from equation [2] are superimposed unto the real time soil moisture data. The superimposed real time soil moisture onto the soil moisture targets are displayed on a screen similar to figure 8.

At the beginning of the irrigation season, the irrigator can manually input the weekly ET values or the values from equation [3] into the SAM setup page. A real time display similar to figure 6 is displayed. With real time displays of the real time data superimposed onto the targets in a graphical representation will allow the irrigator to easily interpret the data.

The flow chart below describes the process by which the SAM software communicates with the field stations. Figure 9 shows a diagram of a field station. The SAM Software will poll data from each station in consecutive order starting with the first field station. After retrieving the data from one field station, the software will move on to the next field station.

SAM Data Acquisition Polling Sequence For Station 1.

1) The Polling Sequence initiates on a fixed time interval.
2) The Acquisition command "Take Current Readings Data Logger 1" along with a command to the master radio to communicate with radio 1 with its MAC address. These two commands are sent by the software out the serial port of the computer.
3) With an RS232 or USB connection to the computer, the Master Radio receives the "Take Current Readings Data Logger 1" message and transmits this message to slave radio 1 as commanded by the SAM software.
4) Slave radio 1 receives the "Take Current Readings Data Logger 1" and passes the message to the data logger via a RS232 cable.
5) Data Logger 1 receives the command "Take Current Readings Data Logger 1" from the slave radio and one by one collects the current data readings from each sensor that is connected to it.
6) Data Logger 1 sends a comma delimited data string back to the SAM software through the radios and serial ports.
7) The SAM software receives the data string, parses the data, and populates the graphical displays and tables in the software viewable by the user.
8) After the SAM software receives the data from data logger 1, it repeats steps 1 through 7 for data logger 2 and slave radio 2.

BLUEBERRY FARM IN WASHINGTON COUNTY, OREGON, CASE STUDY.

A SAM Soil Moisture data acquisition package complete with telemetry and software was installed on a 200 acre blueberry farm in Washington County, Oregon.

The soil unit is Woodburn Silt Loam with less than 3% slope and the soil taxonomic description is Typic Plinthoxeralf. There are two irrigation regimes based on the age of the crop. Two stations, one in each irrigation regime, were installed with 4 Hydra Probe soil sensors, a tipping bucket rain gauge, and an air temperature sensor. Soils data for this location and most locations in the United States are provide for free by the US Department of Agriculture's Web Soil Survey Program, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx .

Figure 7 shows the annual precipitation and ET rate for blueberries in Washington County Oregon (Smesrud 1997). The ET exceeds precipitation from April to October and this generally defines the irrigation season.

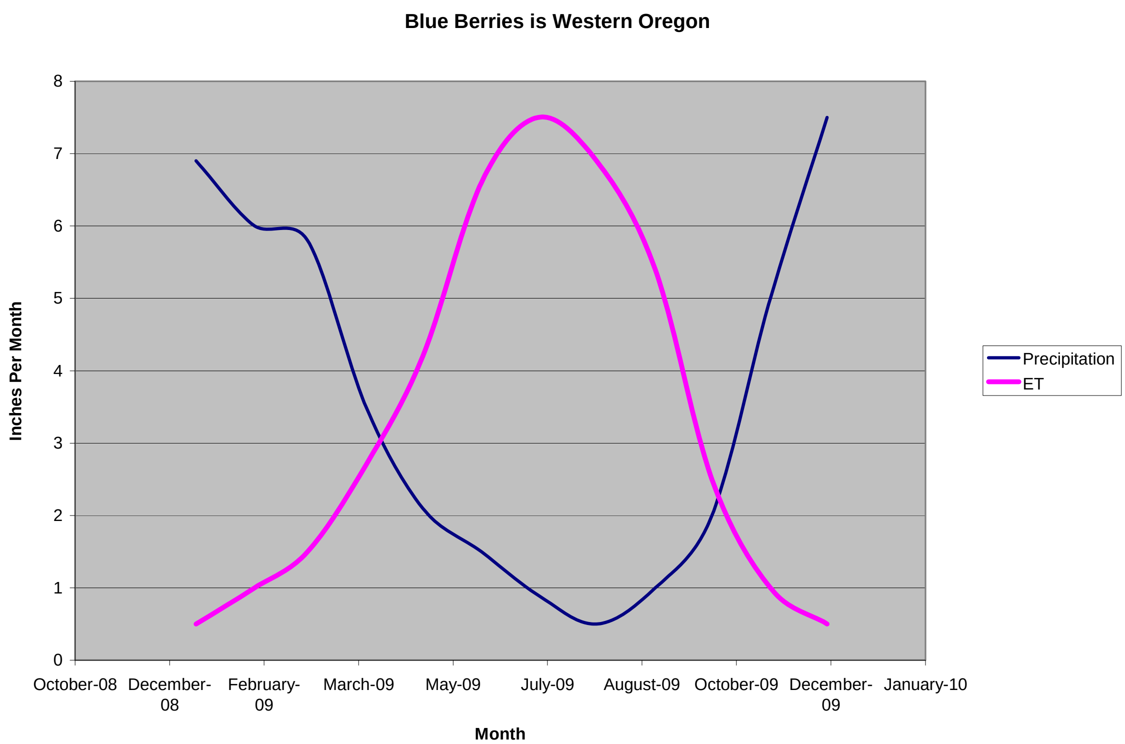

Figure 7. Typical values for monthly ET and Precipitation for blue berries in western Oregon

Each station is located 1 mile away from the computer with the master radio; therefore, this network uses spread spectrum radios. The stations each have one soil profile consisting of 4 Hydra Probes at various depths (2", 8" 16" and 30"). The SDI-12 Hydra Probe Soil Sensors are wired into a multiplexer which is connected to the Stevens Data Logger. Each station is power with a solar panel and the enclosure houses the battery, multiplexer, charge regulator and radio. The radio antennas are mounted to the same mast as the tipping bucket. Figure 9 illustrates one of the field stations with the soil profile.

Using table 1 and table 2, the permanent wilting point is 0.15 the field capacity is 0.3 and the MAD is 50%. The lower soil moisture target as calculated from equation [2] is 0.22.

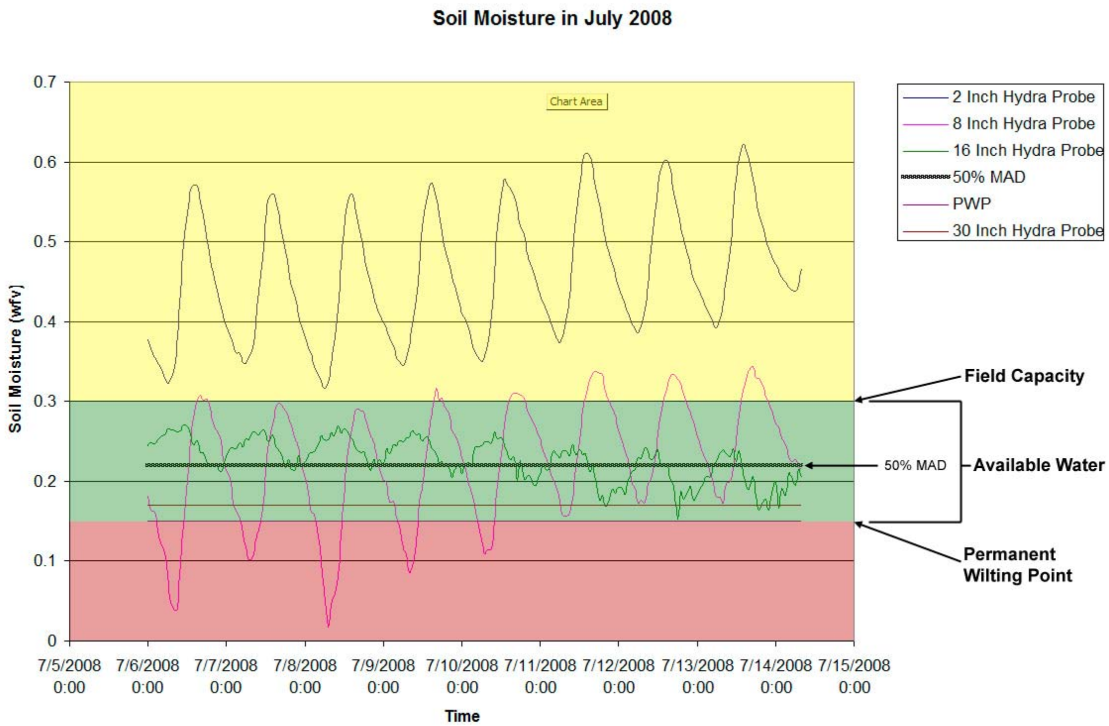

Figure 8. Soil moisture measurements in a profile 2, 8, 16 and 30 inches in depth. Daily irrigation events with subsequent decrease in soil moisture from a high ET rate.

Figure 8 show the soil moisture for a warm week in July 2008. The yellow region of the chart represents soil moisture levels over field capacity, the green region shows the range of soil moistures available to the crop (available water capacity) and the red region is below permanent wilting point. The two inch deep soil moisture values fluctuate the most for downward conductivity and ET and stays above field capacity. This is typical because if the top 2 inches of the soil stayed below field capacity then the root zone would not receive the water. The 8 inch soil moisture values fluctuate widely due to ET and there is a 4 hour lag time between the 2 and 8 inch soil moisture probes from the downward movement time of the wetting front. During extremely hot days, it is not uncommon to have the soil moisture values briefly drop below permanent wilting point between irrigation cycles. The 16 inch soil moisture mirrors the 8 inch values with a 4 hour latency from the soil moisture values above it and the raise and fall of soil moisture values with the irrigation events. The 30 inch deep soil moisture probe below the root zone is remaining constant about 0.10 wfv indicating that water is not peculating downward to the water table.

The solid set sprinklers rotator (with an efficiency of 0.90) apply water daily. For the month of July ET (ET^0 x Kc) is 0.25 inches per day. Using equation [3], the daily water consumption will be 0.28 inches. A weekly display similar to figure 6 is displayed in the software which will allow the irrigator to meet the soil moisture and water application targets.

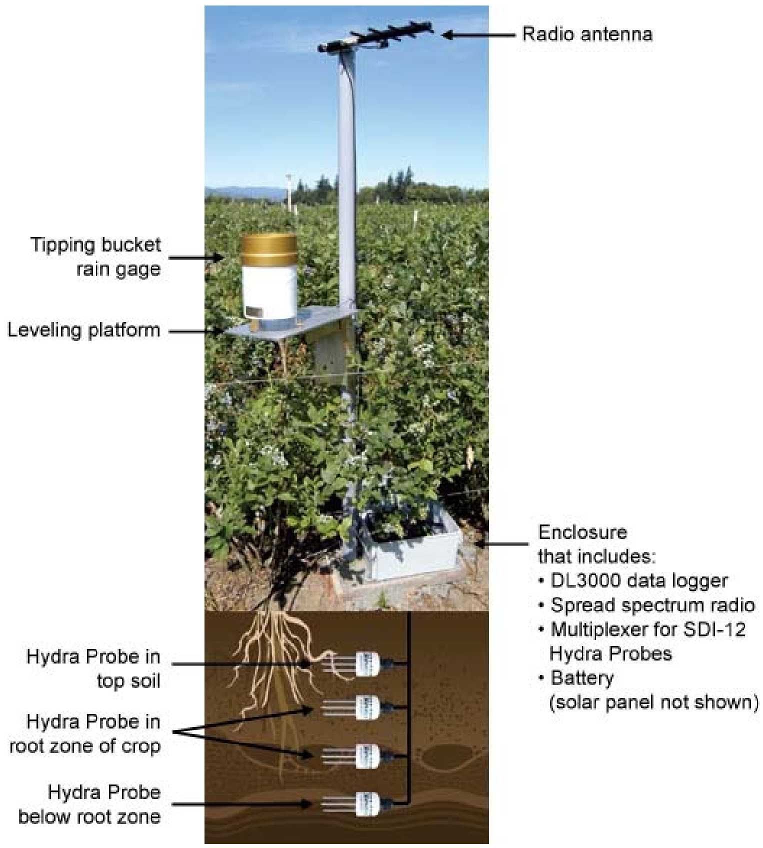

Figure 9. Typical soil moisture profile station which includes four Hydra Probe Soil Sensors, Stevens DL3000 data logger, radio, antenna and accessories.

CONCLUSION

As the demand for water increases, along with the need to protect aquatic habitats, water conservation practices for irrigation need to be effective and affordable. Precision irrigation will optimize irrigation by minimizing the waste of water, and energy, while maximizing crop yields.

The most effective method for determining the water demands of crops is the based on the real time monitoring of soil moisture, and direct water application used in conjunction with the information about soil hydrological properties and evapotranspiration.

The Stevens Agriculture Monitoring data acquisition system wirelessly acquires rain and soil data from the field and integrates the data into water management tools.
The water management tools use information about evapotranspiration, soil and the crop to set specific irrigation targets. These irrigation targets will help the irrigator optimize the amount of water used on a weekly basis. Optimization of irrigation water will increase crop yields while conserving water resources.

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ENERGY RECOVERY FOR SUSTAINABILITY

Joe E. Blankenship[1]

ABSTRACT

Electricity is one of the principal operating costs for irrigation districts. Moving water from the source of supply to the fields to be irrigated requires constant energy. The design of irrigation canals often provide for drops that are used to dissipate increments of excess energy as water accelerates along the canal due to elevation drops in the terrain. Generating electricity at these drops can provide an excellent, and generally unused, opportunity to recover some of the excess gravitational kinetic energy in moving water.

Until now technology has not been available to economically recover energy from drops that of less than about 5 m. The Buckeye Water Conservation and Drainage District ("BWCDD") and NatEl Energy are installing a 20 kW capacity demonstration unit of the Schneider Linear HydroEngine ("SLH") in an irrigation canal in Buckeye, Arizona. This installation has as its purpose the provision of data around reliability and durability of the SLH engine. With O&M data, BWCDD can evaluate other sites for installation of larger generating units to provide sustainable and renewable energy for the District' operation. The SLH is the only technology the District has found that provides economical and efficient recovery of the energy dissipated in irrigation canal drops

In the longer term, the objective for the SLH technology is to provide large dam benefits in hydro generation with significant environmental attributes not available with high dam construction. This would involve multiple installations of the SLH in a stair-step configuration. Meanwhile, BWCDD should benefit economically with sustainable operations using its own infrastructure to generate a large portion of its electrical requirements.

BUCKEYE IRRIGATION DISTRICT — A HISTORY OF PIONEERING

19th Century Pioneering

It was opportunity, not the thought of being pioneers that took the original founders of the old Buckeye Canal west out of Phoenix in the spring of 1885. They chose a location at the junction of the Gila and Agua Fria rivers to locate a dam that would supply a canal for the purpose of "agricultural, milling or mechanical enterprises." Mr. Malin Jackson, one of the founders provided the name "Buckeye Canal" in honor of Ohio, his native state. Original plans were to bring over 120,000 acres under irrigation. This was 19th Century pioneering.

The decades after its founding saw several floods and rebuilding efforts for the Buckeye Canal including change in ownership. One of those changes in ownership came in 1906

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when several farmers wanted to improve service and water supply and purchased the Buckeye Canal Company, renaming it the Buckeye Irrigation Company (BIC). The BIC was set up as a cooperative so that only adjacent land owners could own stock. Later in 1906 the BIC took over the South Extension canal and in1908 assumed operation of the White Tank Canal, bringing the total length of the main canal to 23 miles with the South Extension adding another 7.5 miles.

The drainage district part of the Company came into existence in later years as excess irrigation on higher grounds caused water logging on some of the lower land areas. In 1922, the "Buckeye Water Conservation and Drainage District" ("BWCDD" or the "District") was formed to finance a new dam, install pumps and attempt to correct the water logging problem. To supplement water supply from the river, the District drilled water wells, tapping the aquifer of the Hassayampa River Basin which lies below the Town of Buckeye. In 1950, they started a lateral lining program to reduce the amount of water lost to seepage. 1950 also brought celebration as the District became debt free, paying off the bonds issued for the new dam and improvements beginning in 1922.

BWCDD is an irrigation and drainage district and under Arizona statutes is a municipal corporation of the State of Arizona. The District occupies approximately 22,000 acres with 16,000 acres irrigated and lies within the towns of Avondale, Goodyear and Buckeye, all within Maricopa County. The Buckeye or Main canal is 23.5 miles in length and the South Extension is another 7.5 miles in length.[2]

20th Century Pioneering

In 1966 another pioneering decision was made that proved to be very forward looking. In that year the District contracted with the City of Phoenix to take effluent from the 91st Avenue wastewater treatment plant ("WWTP"). The District recognized the growing need to conserve water, in all of its conditions, and the additional demands that an expanding population would make on fresh water supplies. Knowing that this additional supply would require a shift in types of crops grown, but perhaps a more reliable water supply, the District began receiving WWTP water diverted from the Gila River into the Buckeye canal in 1971. Originally the District began receiving 30,000 acre-feet per year. The amount of effluent received has expanded to 65,000 acre-feet per year as the population of Phoenix has grown and the WWTP has expanded to meet the needs of the larger population. BWCDD pays the City of Phoenix at a rate substantially below the cost of potable water in the area. Currently the District receives or pumps approximately 180,000 acre feet per year with an estimated 50,000 acre feet returned to the Gila River.

The irrigated land around the Canal is used to grow alfalfa, barley, corn, cotton, oats, sorghum and wheat. Because of the restrictions on use of effluent for food crop irrigation, the grain crops are primarily feed for cattle. The area supports a very healthy industry of dairy and cattle feeding operations. Also, the largest supply in the U. S. of quality Pima Cotton comes from the farms along the District's canals.[2]

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[2] BWCDD provided all water supply and area descriptions.

21st Century Pioneering

In early 2007 the managers of the BWCDD saw that controlling electricity costs was going to become a bigger issue in the Districts operating budget. The General Manager of the District, Ed Gerak, began to research the alternatives for generation at the three existing drops on the BWCDD canals. In discussion with the District's electrical consultant, K. R. Saline and Associates, which had long been retained to advise on the District's Hoover Dam power allocation, the consultant provided several alternative methods of generation, including the SLH. After discussions with the management of NatEl, Mr. Gerak and his Board of Directors approved a joint project by BWCDD and NatEl to construct a demonstration project for a nominal 20 kW capacity SLH engine at a drop site on the South Extension of the main canal.

Exhibiting the same pioneering spirit of the previous owners and managers of BWCDD, Mr. Gerak crafted a partnership of site owner, machinery supplier, and civil designer and electrical consultant to design, build and operate a pilot operation on at the South Extension drop. The District would provide the site and modifications of the drop to accommodate the SLH engine: NatEl would contribute the engine as a demonstration of its low cost, low impact, low head hydro generation capability; Stantec, Inc., wanting to be part of the development of a unique green technology would contribute the civil design and K. R. Saline and Associates would contribute the permitting and electrical connection consulting, as well as the Federal Energy Regulatory Commission ("FERC") request for exemption from licensing. The pilot would allow a demonstration of technology that could be implemented at other sites in the District that may have the potential to generate between 200 – 300 kW of additional capacity for the District.

At the end January of 2009 the engine has been designed, manufactured and assembled. The civil design has been completed and the FERC request for exemption has been filed. At each stage of the process, the partners have learned how to deal with the technology and the regulations for bringing about a methodology of providing a low cost option for electrical generation in low head environments. The District is currently (April 15, 2009) waiting for notification of the granting of an exemption from FERC to complete the project.

Beyond Buckeye, the initial applications of the SLH are scheduled to be in irrigation canals and water supply conduits. Smaller machines may be economical in wastewater treatment plant outfalls. While this market is being cultivated, NatEl will begin to work with developers that wish to add generation to the approximately 75,000 non-powered existing dams in the U. S.

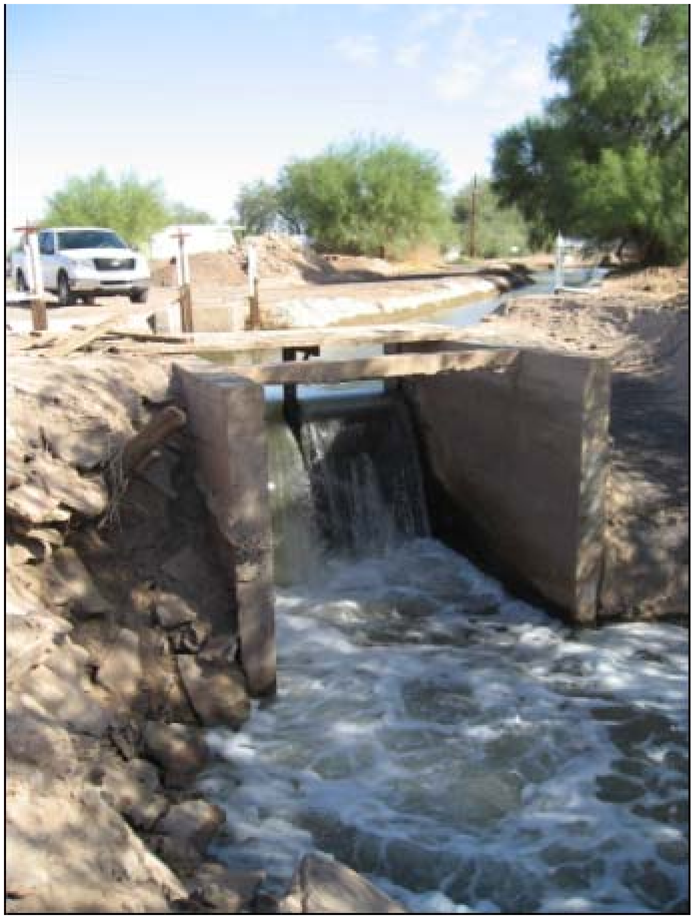

Figure 1. South Extension canal drop

PROOVING THE HARD SCIENCE — MACHINERY DESIGN AND ELECTRICAL GENERATION

The design of the SLH engine, as well as its materials of construction, methods of manufacture and assembly are a matter of established engineering and design. These designs provide for efficiency of operation as well as durability and reliability. The design of the BWCDD demonstration unit is such that it is scalable from 20 kW up to 1,000 kW of nominal capacity. The cost estimates from the current design effort for the SLH system, which includes the engine, generator, inlet gates, penstock, draft tube and PLC (essentially a system ready for installation), are indicated at a capacity cost of between $1,000 and $1,500/kW. The generator is off the shelf, and the other parts lend themselves to stamping, bending and simple milling that does not require expensive multi-axis CNC machines. The PLC is a special design that will meet SCADA requirements and can be adopted for automated and remote operation as well as control of multiple units in series.

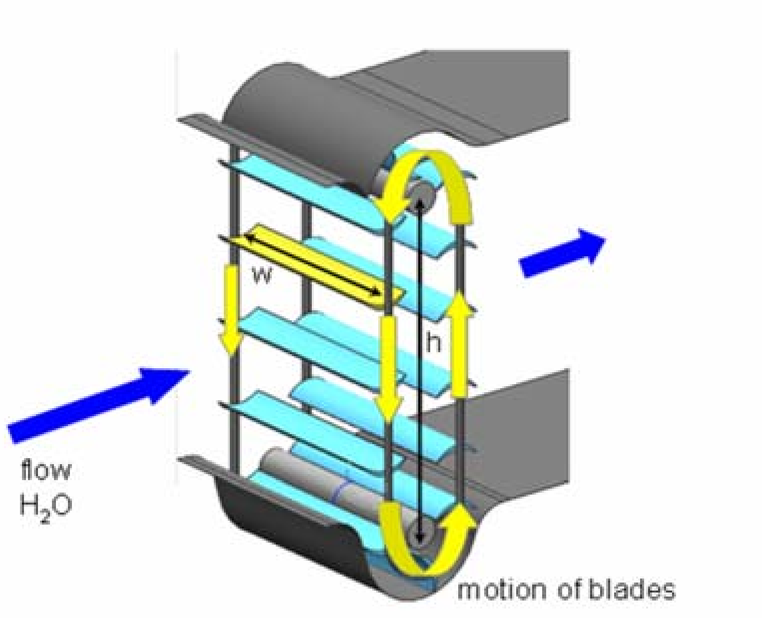

Figure 2. Working Configuration of the SLH machine

The SLH operates in a significantly different manner than a rotary turbine. Water impacts a series of foils that are linked by chain or belt. The foils travel in a linear direction up and down and over the bottom and top shafts. The upper shaft is connected to a speed increaser and generator, providing the electrical output. The significant difference between this design and a rotary turbine is that the SLH can handle large volumes of slow moving water and convert the kinetic energy to electricity with efficiencies of over 80% across a broad range of heads and flows.

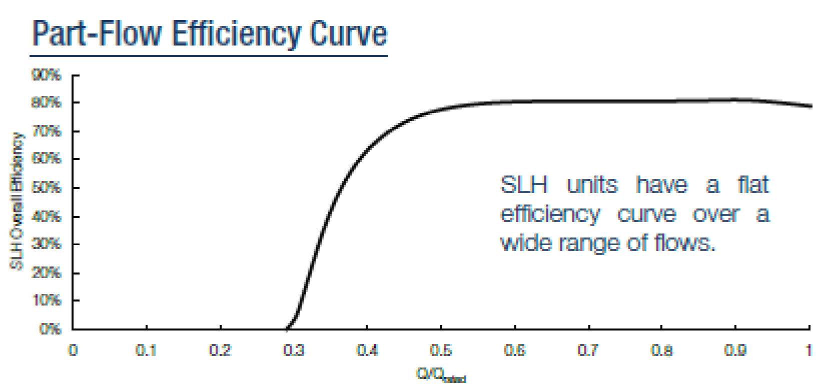

Figure 3. Efficiency curve of the SLH engine

CONVINCING THE SOCIAL SCIENCES — ECONOMIC, REGULATORY AND ENVIRONMENTAL ASPECTS

Economics of SLH in Low Head Hydro

Favorable economic results generally are when there is a net monetary income. For the regulatory community, favorable economics means all rules are complied with. And for the environment, a project must look at life cycle effects to be sure that air, water, soil, plants and animals are not adversely impacted, in addition to considering human safety factors, productive land use and the recycling of all construction materials.

In the U. S. there has been very little development in low head hydro over the past 50 years. Some of this may be attributed to the social forces that have put hydro development in the environmentally unfriendly category, but a great deal has to do with the fact that using the standard turbine technologies was too expensive to design, build and install. Generally, an installation of a turbine meant design for a specific application and then manufacturing one unit on a multi-axis CNC machine. The civil works had to be designed to carry the heavy loads of the machinery as well as the constant force of falling water.

In the initial phases the SLH will not escape some unfavorable attitudes held about hydro generation. Attitudes will change only after favorable environmental benefits are demonstrated. As to the economic feasibility, design and cost estimates have confirmed a realistic opportunity to again look at low head hydro as a means of meeting the renewable energy needs of the nation. Since the engine can be produced by standard stamping, forming and machining methods and the engine housing, penstock and draft tube are fabricated of heavy steel, the cost of capacity can be competitive with coal fired plants and nearly as competitive as combined cycle gas turbines. With low capital cost and renewable flowing water providing low or no cost fuel, the overall cost of electricity can be very competitive.

To determine the cost competitiveness for the SLH, data requirements are the system head, flow and duration of the flow. A review of the record of water flows over a drop for one or two years will provide sufficient data to calculate a duration curve. With this data, along with efficiency of conversion, the calculation of the annual amount of electricity generated can be made. Revenue is determined by the kWh production and the feed in tariff at the utility.

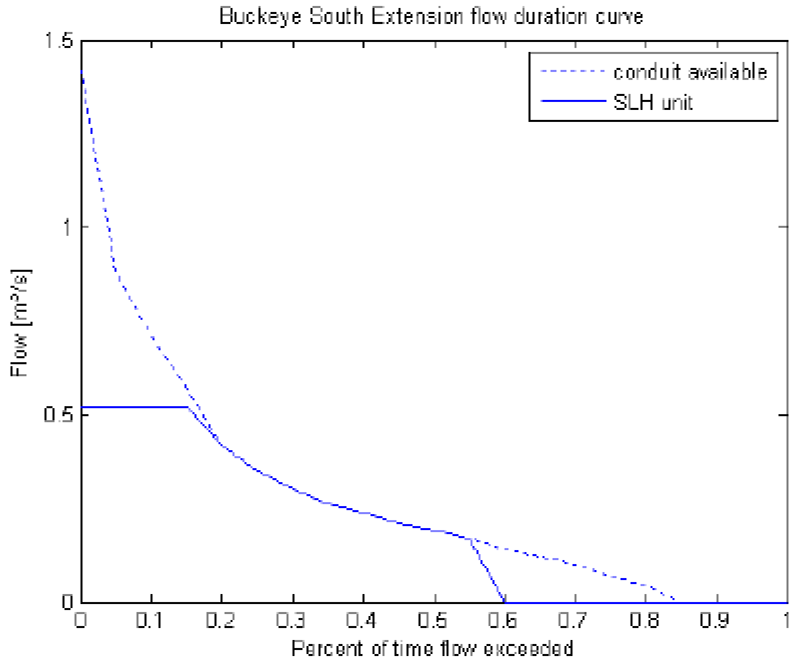

Figure 4. Flow Duration Curve for South Extension Drop

The flow duration curve (Fig. 4) provides the basis for a pro forma operating statement for the demonstration unit at BWCDD. The engine design is for 20 kW of capacity at 4 m of head and flow of 0.52 m^3/s. The actual drop is 2.74 m and average flow is 0.29 m^3/s. With the duration curve providing time and flow the calculation of capacity utilization of the Buckeye pilot is approximately 25%. Under these conditions the projected production is 38,000 kWh/yr against a design capacity of 158,000 kWh/yr based on a 90% availability.

There are several things that will change the actual economic outcome of the BWCDD installation. The District has the opportunity to lower the level of the down stream pool to make the elevation change larger. Another change would be to alter the schedule of water directed through the drop to have a longer period of flow through the SLH. Either of these would impact the actual results to make the installation more favorable than in the forecast.

Economic considerations for SLH sizes above 20 kW are more favorable. A scaling study has provided system cost estimates for all sizes up to 1000 kW. The lowest cost per kW for the machinery is estimated to be in the 200 kW – 400 kW range. Adding in civil design, construction and permitting the all-in estimates for a 200 kW capacity installation is likely to range from $1,850 - $2,000 per kW of capacity. Operation and maintenance cost is estimated to be approximately $0.02 kW/h. The biggest variable will be the amount of capacity utilization experienced. NatEl estimates of lifecycle cost per kWh based on a 20 year life, 8% cost of capital and $0.02 O&M is shown in Fig. 5.

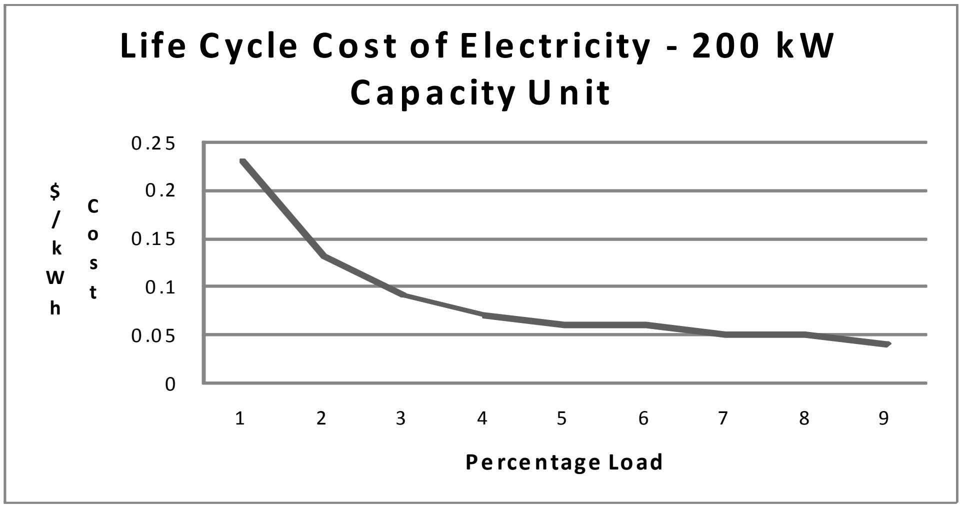

Figure 5. Estimated SLH kWh lifecycle cost based on percentage load

Beyond the price-cost relationship cost of electricity, the economic benefits are likely to be enhanced by the incentives that continue to develop around production of renewable energy. For small hydro, the Federal Tax Code allows taxable entities to take an Investment Tax Credit ("ITC") of 10%, or alternatively, an approximate $0.01 kW/hr production tax credit ("PTC") for ten years. For irrigation districts these incentives will generally not be available, but there may be ways to monetize the PTC for a portion of the cost of an installation. More readily monetized are the Renewable Energy Credits ("RECs") generally bought by utilities to meet Renewable Energy Standards ("RES"). These REC's will become more valuable as a cap-and-trade program for carbon offsets become more prevalent. A cap-and-trade system has been instituted in California and is indicated to be an integral part of the Western Climate Initiative of seven western states. Under the most favorable circumstances, low head hydro may provide between two and ten cents ($0.02 - $0.10) per kWh in RECs over the coming years.

Regulatory Considerations

Regulations tend to reflect the social considerations in the community in which we live. Regulation of hydro electric generation reflects society's attitudes about the environmental effects of generation using high dams that have caused river obstructions to fish passage or riparian ecological impacts. These concerns are reflected in the factors required for an application for the FERC exemption for a low head hydro exemption. An Environmental Impact Statement is not required by statute for a low head hydro exemption. However, FERC does require an Environmental Assessment and notification of potentially impacted agencies and organizations of the intent to build a facility in a waterway, even a conduit such as an irrigation canal or aqueduct.

This number of parties to be notified in a FERC exemption request illustrates the lengths to which regulations allows participation in the approval process. The process also can provide potential delays and alterations as comments and/or objections come from any of the notified parties. In addition to the U. S. Fish and Wildlife, State Game and Fish departments and state permitting agencies, archeological discoveries and historical agencies may have effect the schedule. Consideration for Native American lands must also be taken into account. A requirement by FERC is a GIS map of the site, with ownership of attached parcels identified to reflect neighborhood impacts. Under normal circumstances, the cost of the preparing the FERC exemption request as well as the time required for FERC approval and post approval conditions could make a facility as small as the one at Buckeye too expensive for a reasonable economic return.

Regulation of projects to prevent environmentally damaging events is a concept we approve of. What is required is for the process to work efficiently and timely to realize the full benefits of a project's possibilities. For the small hydro construction process, obtaining the FERC exemption is **THE** critical path element in going from conception to operation.

Before January of 2009 there were only ten exemptions for low head hydro generation issued nationally over the past four years[3.] An analysis shows only four of those as Conduit exemptions. However, two Conduit exemptions have been issued in January of 2009[3]. One of the 2009 issued projects took over nine months from application to granting of an exemption. The second took five and a half months which is what is expected if there are no protests or motions to intervene. In addition to the processing time, a condition of approval is filing of final construction drawings 60 days prior to beginning construction.

The preparation, processing and post approval conditions of the FERC exemption can take several times longer than the design, installation and commissioning of a project, particularly if the machine is already manufactured. In economic terms this could mean a delay by several months of revenue received from a project.

Environmental Considerations

The SLH has been designed to mitigate several potentially harmful effects to the environment. For irrigation canals, since no additional dams or impoundments are to be constructed, there may be very little environmental impact to come from installing a SLH. There are no Fish and Wildlife considerations and endangered species concerns should have been cleared in the construction of the canal and its drops. The biggest environmental advantage is the positive benefit to be gained by using existing infrastructure of irrigation canals and non-generating low head dams to offset many of the negative impacts from coal and natural gas fired electrical generators. These benefits come about while recovering energy that is currently being wasted.

As legislation for national renewable energy standards are debated and regional cap-and-trade programs are enacted, the drive for carbon dioxide reduction will become more intense. The ability to accomplish a part of the CO_2 reduction objective by using existing infrastructure, and at the same time derive significant economic benefit will become more appealing. In an attempt to quantify the potential for reducing CO_2 emissions for the in-

[3] www.FERC.gov/industries/hydropower.asp

conduit market of irrigation districts and water supply we examined the carbon dioxide emissions per MWh of a local utility:

> Average CO_2 emissions from existing coal fired units - 0.98 metric tons/MWh
> Average CO_2 emissions from existing gas CC – units – 0.42 metric tons/MWh
> Average CO_2 emissions from existing gas CT units - 0.61 metric tons/MWh[4]

At NatEl, we believe the potential capacity of low head hydro installations in irrigation and aqueducts in the western states regulated by the Bureau of Reclamation to be approximately 4,000 MW. At 50% capacity utilization the annual carbon dioxide reduction may potentially be around 17,520,000 metric tons of CO_2 per year if only coal fired plants are considered. With an average CO_2 emission of Combined Cycle and Combustion Turbine units of 0.50 metric tons/MWh of carbon dioxide emissions, the potential for carbon dioxide reduction may be one-half of coal, or 8,760,000 metric tons of CO_2 per year.

The design considerations for the machinery and surrounding housings, penstock and draft tube encompass a “cradle to cradle” philosophy - make everything recyclable. Of the parts and pieces in the SLH system, we estimate that 98% of the materials of construction can be recycled. Of the cement and mechanics of water control in the surrounding housing and structures, that may be true as well.

THE END GAME — LARGE SCALE BENEFITS, SMALL SCALE IMPACTS

The main attraction for BWCDD in partnering with NatEl for a SLH demonstration plant installation is the availability of a technology that can provide economic generation in several more drops in its canal system, thus offsetting its electrical costs by as much as one third. Another attraction was the District’s engrained pioneering vision for adoption of this technology worldwide in a system that could bring environmentally friendly electricity generation too many underdeveloped parts of the world. The technology provides a ready alternative to high dam construction that has so many detrimental environmental effects wherever they are installed. The litany of complaints about hydro power using high dams and impoundments are many: Flooding of human and fauna habitat; uprooting families and destroying farm land and grazing areas; impeding fish passage for spawning and migration; forever altering canyon and valley ecology and geographic attractions, as well as others. From its design inception, NatEl has incorporated physics and aquatic physiology criteria to achieve many of the power generation attributes of high dams with a minimum of environmental disturbances and impacts. Through a method called Linear Reservoir Routing (“LRR”), studies indicate that placement of strategic small dams along a long river path can provide up to 80% of the power of a high dam while flooding as little as 5% of the land.

This conclusion has been developed after studies of a dam already installed as well as with a proposed installation. A study at the University of North Texas compared the cost and effects of a high dam built in Nepal with the estimated economic, ecological and

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[4] Arizona Public Service; Resource Plan Report; January 29, 2009; p.34.

social costs if a LRR system of stair-step dams had been constructed.[5] The study of the dam in Nepal concluded that the return on investment in economic measures could have possibly been several times that provided by the actual installed conventional high head structure, and the social, ecological and societal benefits would have been dramatically different based on lower human displacement and sustaining fishing and farming that had occurred for centuries[5].

A controversial river valley program being considered in the 1970s was in the St. John River Basin of Maine. The plan as proposed would build two high dams; Dickey Dam at about 90 meters of head and the Lincoln School Dam at about 30 m of head. From the two dams, 88,240 acres of wilderness, agricultural and habituated land would be flooded for power generation. The installed capacity of these two dams would have been 830 MW. Dr. Daniel Schneider and Emory Damstrom presented a paper at the Waterpower '79 International Conference on Small Scale Hydropower that illustrated a prospective series of eight dams each having a head of 5 to 8 m. Pumped storage reservoirs were added to provide peaking capability and control flooding. This proposal would have flooded approximately 4,500 acres, or 5% of the high dam amount and could produce 80% of the power stipulated in the high dam approach[6]. The dams were not constructed and the area was converted to a national wilderness area.

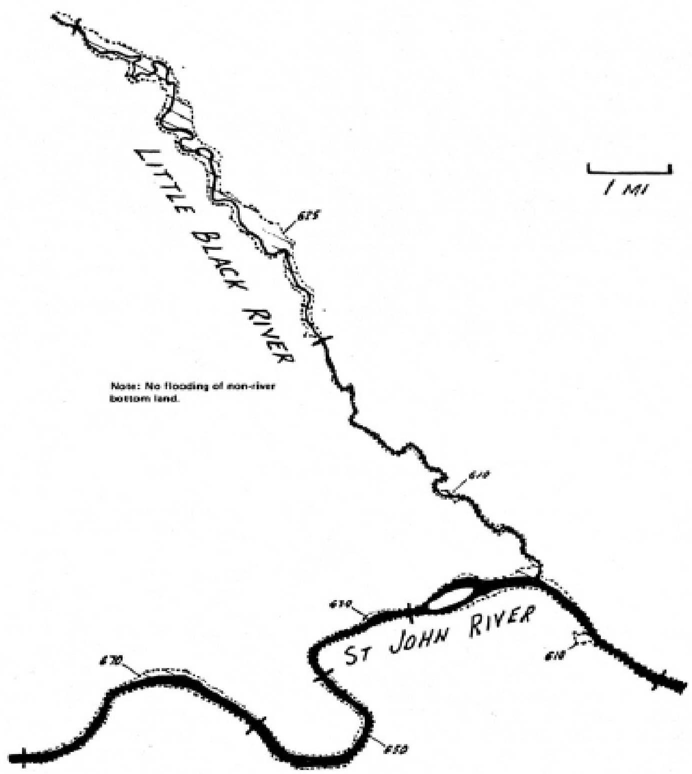

Figure 6. Illustration of low head reservoirs placed in series.[6]

[5] Nieswiadomy, Dr. Michael; Wang, Hana; "The Benefits of Sustainable Hydropower Using Low-Head Dams in Stair-Step Series"; University of North Texas; Department of Economics; July 17, 2008.
[6] Schneider, Daniel J,; Damstrom, Emory K.; "The Schneider Engine: Performance and Application For Hydropower"; Waterpower '79; October 1-3, 1979.

To obtain high dam benefits with low dam designs requires a programmatic demonstration of the SLH attributes of efficiency, durability, reliability, fish passage, balance of system cost and cost of manufacture and installation. The demonstration site at BWCDD is a small step in the program of demonstration, scaling and implementation of larger size systems.

CONCLUSION — DEMONSTRATION OF THE INSTALLATION BENEFITS TO BWCDD

The data necessary to calculate SLH efficiency in the production of electricity has been gathered in laboratory and pilot plants previously installed. The objectives for the installation at BWCDD of a demonstration of the SLH technology are to provide data on reliability and durability for design components and use machine engineering data of the 20 kW engine to scale the system to larger sizes. By providing access to its site at the South Extension, BWCDD will end up with ownership of the generating plant as well as demonstrated capability for installation of several additional sites.

If all of the potential installations are made at BWCDD, the District may offset up to one-fourth of its electrical costs into the indefinite future. This becomes a permanent hedge of electrical costs for that portion of its operating expense. In the District's pioneering tradition it is using its own resources to provide a long term contribution to systems that support an expanded, sustainable future.

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ESTIMATION OF POTENTIAL FOR MANAGEMENT-BASED PRACTICES TO MEET IID ON-FARM WATER CONSERVATION GOALS

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ABSTRACT

The Imperial Irrigation District of Southern California (IID) is embarking on an ambitious program to conserve 303,000 acre-feet per year for transfer to other Colorado River water users in California. Conservation will be achieved through a combination of system and on-farm improvements. On-farm conservation of approximately 200,000 acre-feet of water per year will be achieved through a voluntary program in which participants have the option to choose which conservation measures to implement on individual fields based on incentive offerings.

In 2007, IID completed the Efficiency Conservation Definite Plan (Definite Plan), which identifies likely components of the on-farm program, including expected on-farm conservation measure implementation by participants for varying incentive offerings. Expected increases in irrigation performance, reductions in farm deliveries, and corresponding implementation costs were estimated for each field for each season and compatible conservation measure.

Estimation of delivery changes was accomplished by modeling performance increases as a function of the crop, soil, and irrigation method at the field; the conservation measure selected; and the historical irrigation performance of the field. The model was developed, in part, based on simulations of surface irrigation performance across a range of inflow rates and cutoff times for historical irrigation events monitored by IID.

This paper provides a brief background and overview of the on-farm component of the Efficiency Conservation Definite Plan, describes the evaluation of management-based conservation measures such as irrigation scheduling, and compares conservation estimates for management-based conservation measures to other conservation measures evaluated as part of the Definite Plan.

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BACKGROUND AND OVERVIEW

The Imperial Irrigation District of Southern California (IID) diverts approximately 3.1 million acre-feet of Colorado River water annually to irrigate approximately 475,000 acres of agricultural lands (Figure 1). The top nine crops by water use in IID in recent years are alfalfa, Bermuda hay, Sudan, sugar beets, wheat, carrots, onions, and lettuce. Soils range from heavy, cracking clay to sand but are dominated (> 80%) by cracking and heavy non-cracking clay soils. Primary irrigation methods employed by IID growers are graded border (locally called "flat") and graded furrow (locally called "row"). High distribution uniformity and application efficiency are possible due to the heavy cracking soils for which infiltration is relatively insensitive to intake opportunity time. The primary on-farm loss is tailwater (surface runoff), which flows to the Salton Sea, a saline lake supplied mainly by irrigation drainage.

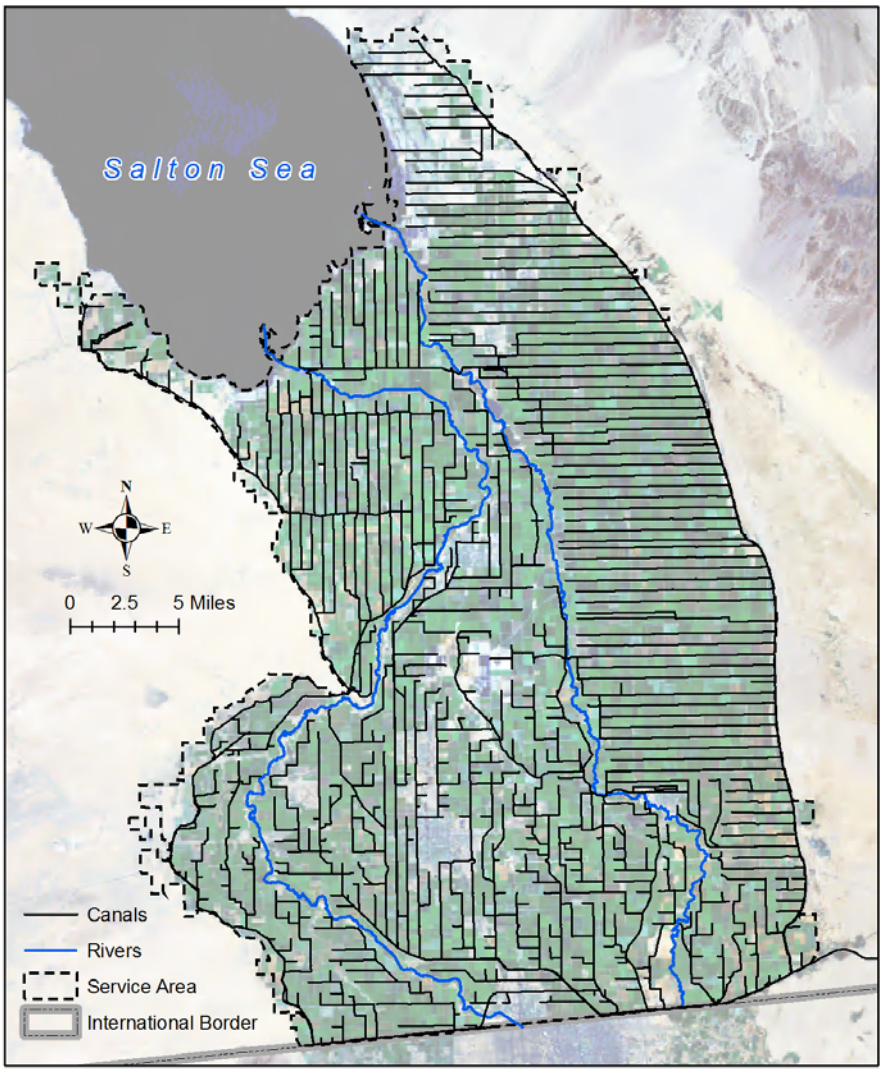


Figure 1. Imperial Irrigation District

In 2003, IID entered the Quantification Settlement Agreement and Related Agreements (QSA), agreeing to the transfer of 303,000 acre-feet annually to other Southern California Colorado River water users through a combination of system and on-farm conservation projects aimed at increasing on-farm irrigation and distribution system efficiency. As a condition of the agreements, at least 130,000 acre-feet must be generated through the implementation of on-farm conservation measures (CMs). The ramp-up schedule of transfer amounts is shown in Figure 2.

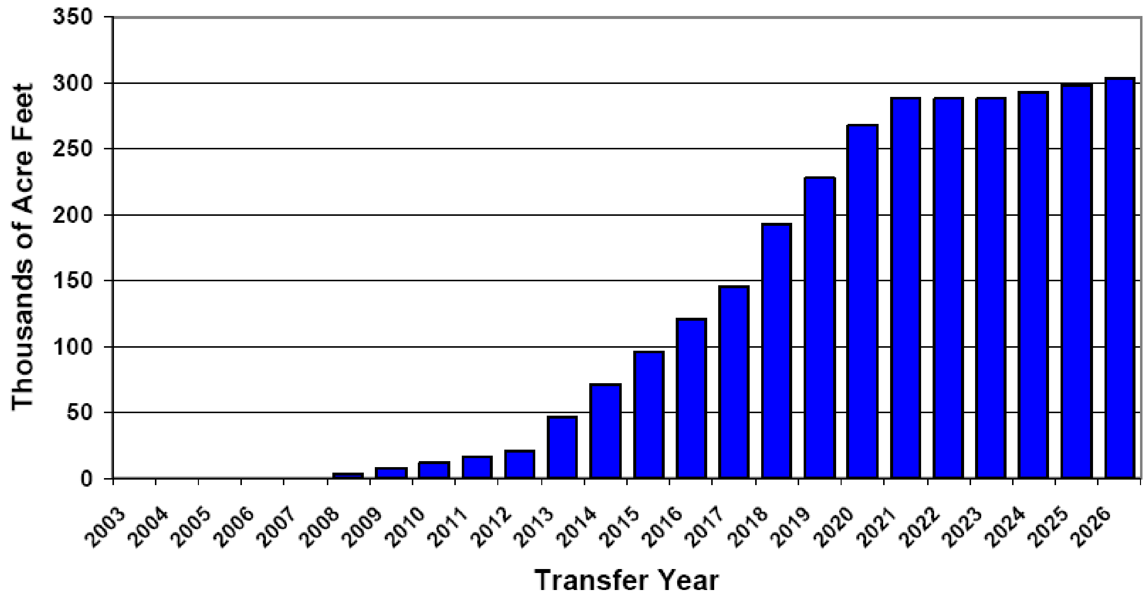


Figure 2. QSA Transfer Schedule

In 2007, IID completed its Efficiency Conservation Definite Plan (Plan), which identifies the most cost effective mix of on-farm and system improvements needed to satisfy transfer obligations while keeping expenditures below available transfer revenues. On-farm participants in the transfer program will be provided incentives to implement CMs to achieve conservation goals. The Plan identified numerous CMs that growers are likely to consider. Among those CMs growers expressed interest in implementing were management-based CMs aimed at increasing irrigation efficiency through decreased tailwater production. CMs evaluated under the Plan are listed in Table 1[5].

In particular, interest was expressed in improving surface irrigation methods through irrigation scheduling and event management. Scientific Irrigation Scheduling (SIS), as evaluated under the Plan, includes decisions made prior to placing irrigation orders for individual fields including the timing, duration, and amount of water aimed at minimizing tailwater production while satisfying crop water requirements. Scientific Event Management (SEM), as evaluated under the Plan, includes decisions made after the start of an irrigation event based on observed advance, infiltration, and runoff aimed at

[5] The CMs evaluated under the Plan were selected to represent the range of costs and efficiency gains generally available to IID growers. In implementation, it is expected that growers will be allowed wide latitude in selecting CMs including but not limited to those considered during planning.

minimizing tailwater production while providing adequate infiltration to meet crop water needs.

Table 1. Conservation Measures Evaluated as Part of the Plan

Conservation Measure	Configurations	Method of Analysis for Conservation Potential
Center Pivot	3 field sizes, 8 crop-irrigation method combinations	Potential application efficiency based on distribution uniformity, results of on-farm demonstrations.
Level Basin	10 basin sizes, flexible and standard delivery schedules, 8 crop-irrigation method combinations	Surface irrigation modeling (SIRMOD)
Micro Irrigation	3 field sizes, with and without reservoir, rental or purchase, 8 crop-irrigation method combinations	Potential application efficiency based on distribution uniformity, results of on-farm demonstrations.
Minor Management and Physical Improvements	3 field sizes, 8 crop-irrigation method combinations	Professional judgement based on results of other conservation measures.
Scientific Irrigation Scheduling	3 field sizes, 8 crop-irrigation method combinations	Surface irrigation modeling (SIRMOD)
Scientific Event Management	3 field sizes, 8 crop-irrigation method combinations	Surface irrigation modeling (SIRMOD)
Sprinkle Irrigation	3 field sizes, with and without reservoir, rental or purchase, 8 crop-irrigation method combinations	Potential application efficiency based on distribution uniformity, results of on-farm demonstrations.
Tailwater Recovery Systems with Reservoirs	3 field sizes, 2 reservoir sizes, 2 pipeline lengths, 8 crop-irrigation method combinations	Operational model of TRS operation for historical irrigation events, results of on-farm demonstrations.
Tailwater Recovery Systems without Reservoirs	3 field sizes, 2 pipeline lengths, rental or purchase, 8 crop-irrigation method combinations	Operational model of TRS operation for historical irrigation events, results of on-farm demonstrations.

Each CM was characterized with respect to potential increases to irrigation performance, defined as the ratio of crop evapotranspiration of delivered water (ET_{dw}) to irrigation deliveries (DW). This ratio is called the Consumptive Use Fraction, or CUF (CUF = ET_{dw}/DW). Parameters were developed to estimate increases in the CUF for individual crop-seasons across the range of crops, irrigation methods, and soils in the Valley (Figure 3). Additionally, parameters were estimated for each CM to estimate implementation costs for individual crop seasons (Table 2).

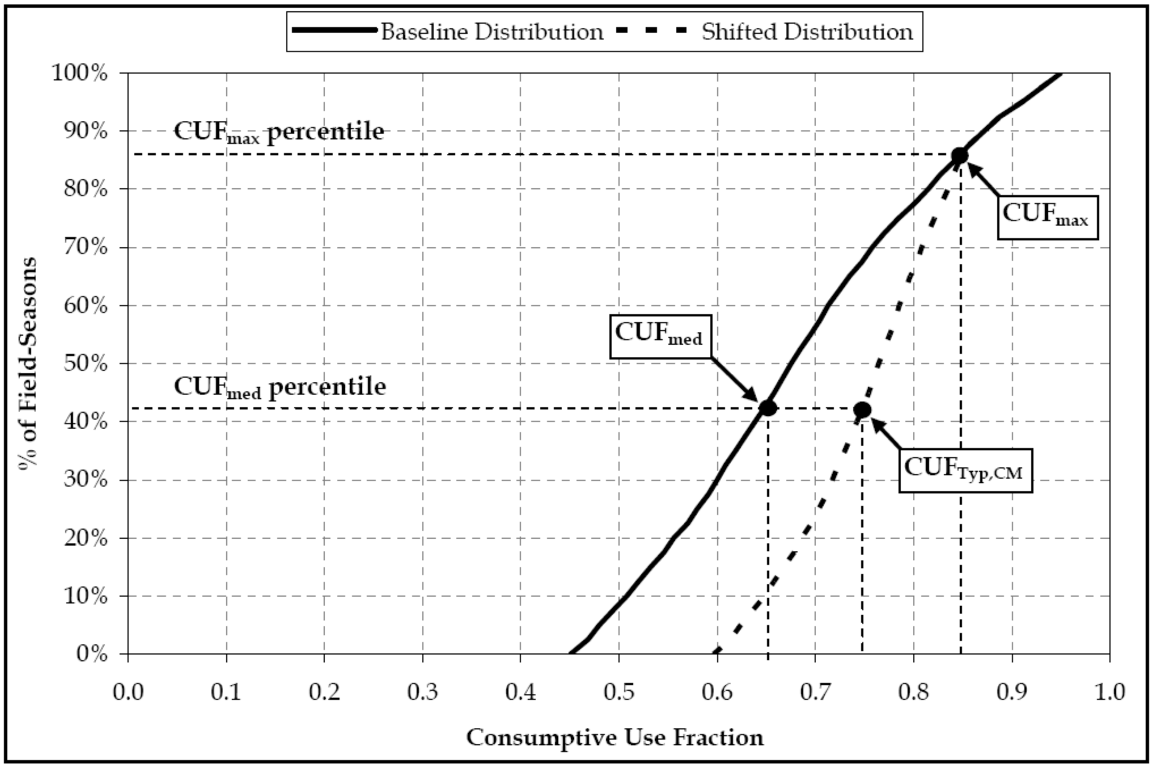


Figure 3. Example Increase in Consumptive Use Fraction Resulting from CM Implementation for a Particular Crop, Soil Type, Irrigation Method, and Conservation Measure.[6]

Table 2. CM Cost Characterization Parameters

Annual Capital and Maintenance Cost per Acre
Annual Capital and Maintenance Cost per Field
Seasonal Operations Cost per Acre
Seasonal Operations Cost per Field
Seasonal Additional Benefit per Acre

[6] CUF_{max} percentile – Percentile at which maximum CUF occurs, above which an increase in seasonal CUF would not be expected for a given CM.
CUF_{max} – Representative CUF at the CUF_{max} percentile for a particular crop, soil type, irrigation method, and CM combination.
CUF_{med} percentile – Median percentile for CUF values expected to increase as a result of CM implementation (equal to ½ of CUF_{max} percentile).
CUF_{med} – representative CUF at the CUF_{med} percentile for a particular crop, soil type, and irrigation method.
$CUF_{Typ,CM}$ – representative CUF at the CUF_{med} percentile for a particular crop, soil type, irrigation method, and CM combination.

EVALUATION OF PERFORMANCE INCREASES AND ASSOCIATED DELIVERED WATER REDUCTION FOR MANAGEMENT-BASED CONSERVATION MEASURES

Changes in irrigation performance were estimated by estimating the increase in CUF for each historical crop season (over 103,000 crop seasons were evaluated). Then, the increased CUF was used to update the water balance for each crop season (Figure 4). Changes in deliveries were estimated by assuming little or no change in evapotranspiration of delivered water (ET_{dw}). The deliveries following CM implementation are estimated as the historical ET_{dw} divided by the estimated CUF after CM implementation.

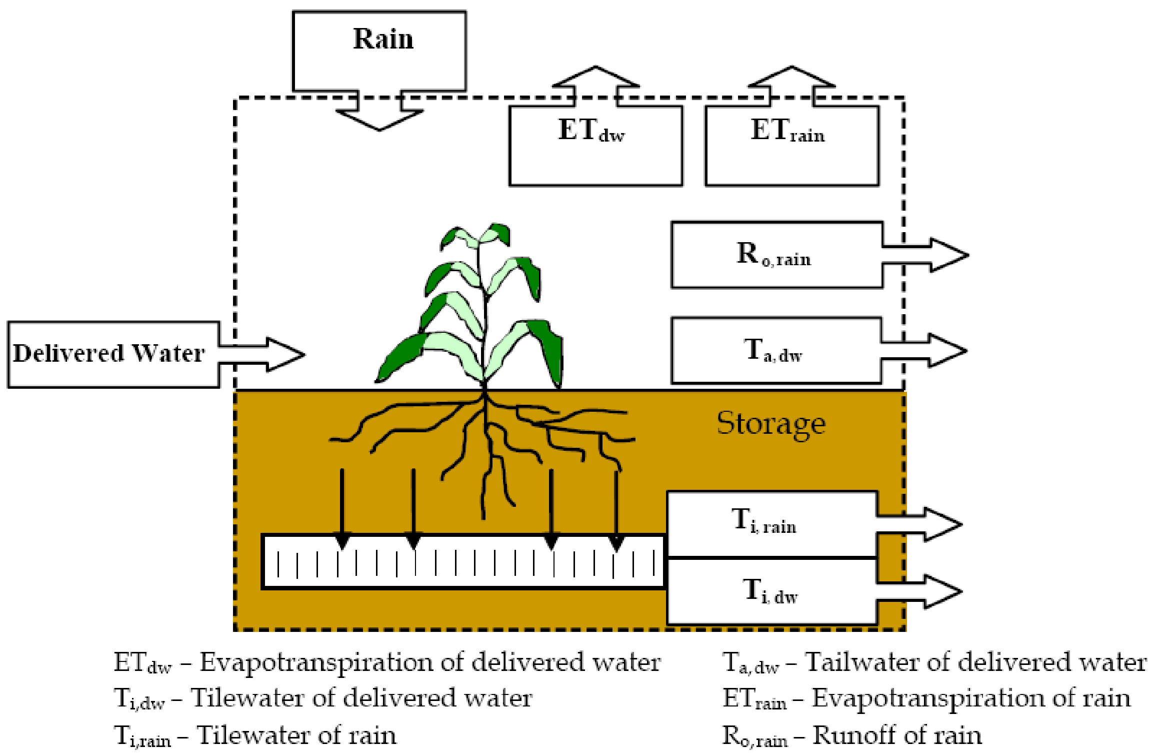


Figure 4. On-Farm Water Balance Conceptual Diagram

Potential CUF increases for irrigation scheduling and event management were estimated using the SIRMOD surface irrigation model developed at Utah State University. SIRMOD simulates advance, recession, infiltration, runoff, and performance indicators for surface irrigation events and can be used for simulation, evaluation, and design (Figure 5). The model was calibrated for 21 historical flat irrigation events and 13 historical row irrigation events. Calibration was accomplished using delivery and tailwater hydrographs collected by IID's Irrigation Management and Monitoring Unit (IMMU) as shown in Figure 6. For each event the model was calibrated to estimate the soil intake characteristics (Figures 7a and 7b for row and flat events, respectively). Light, heavy, and heavy cracking soil classes, shown in Figures 7a and 7b, were preliminarily assigned based on the NRCS soil survey of the Imperial Valley.

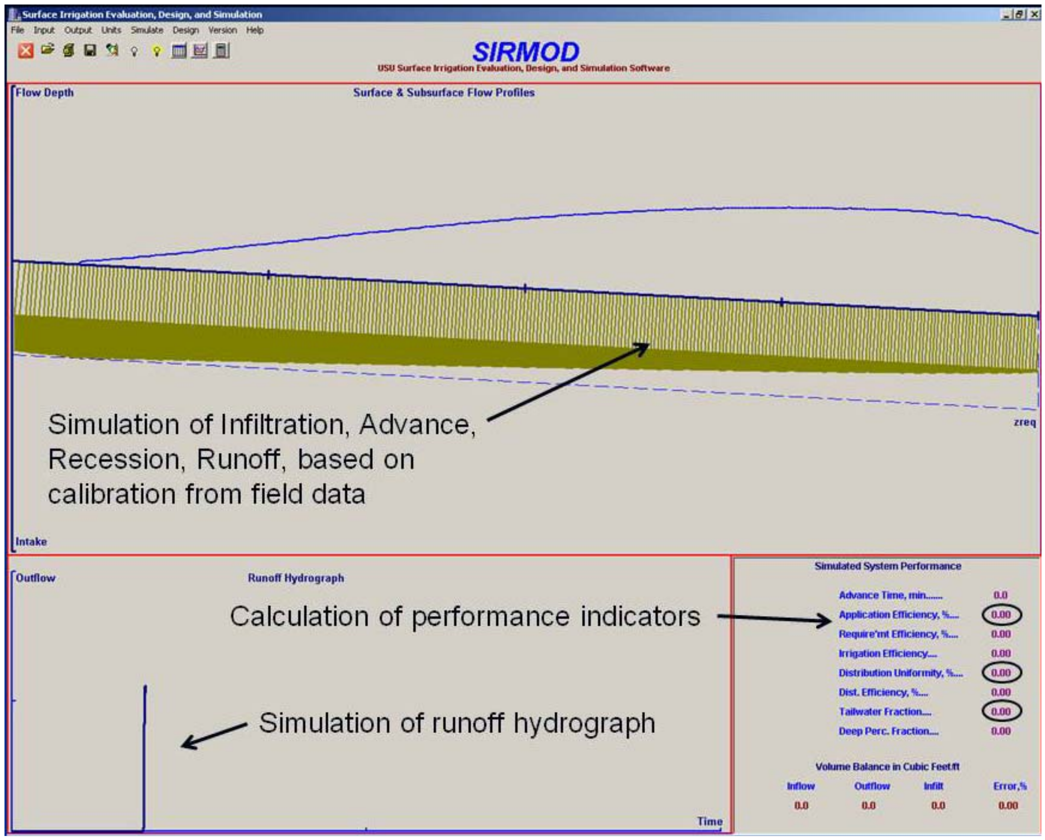


Figure 5. SIRMOD Screen During Event Simulation

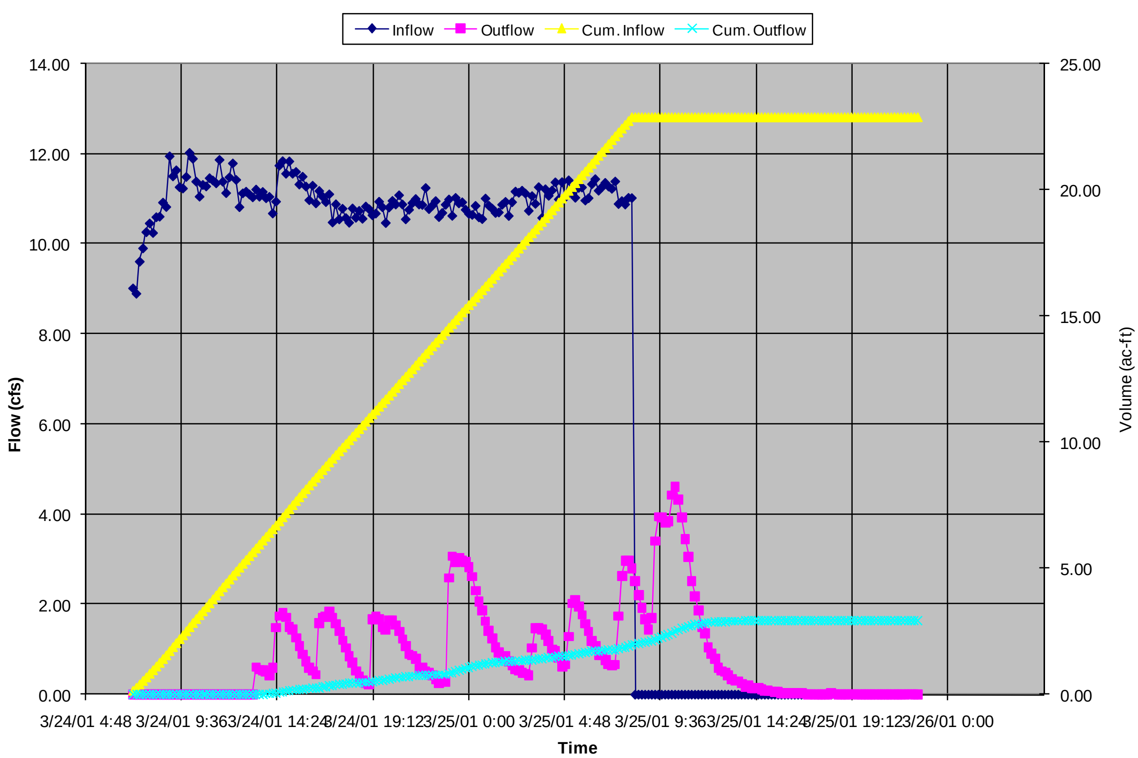


Figure 6. Sample Delivery and Tailwater Hydrograph for a Flat Irrigation Event

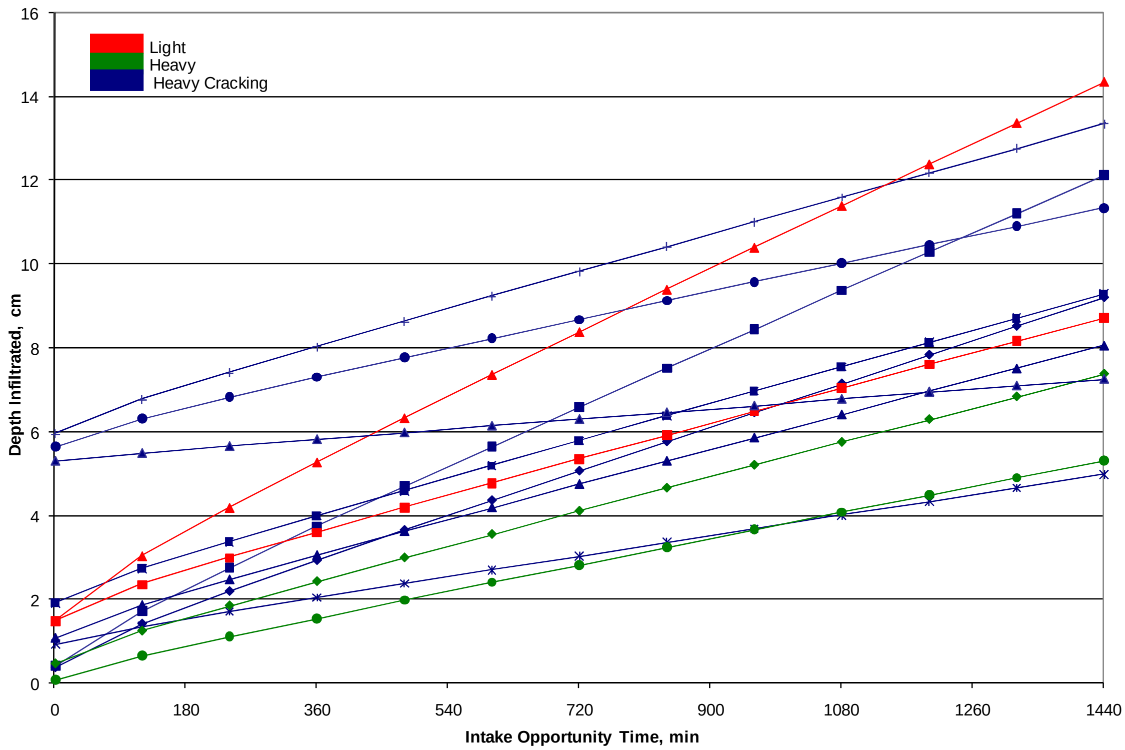


Figure 7a. Calibrated Intake Curves, Row Events

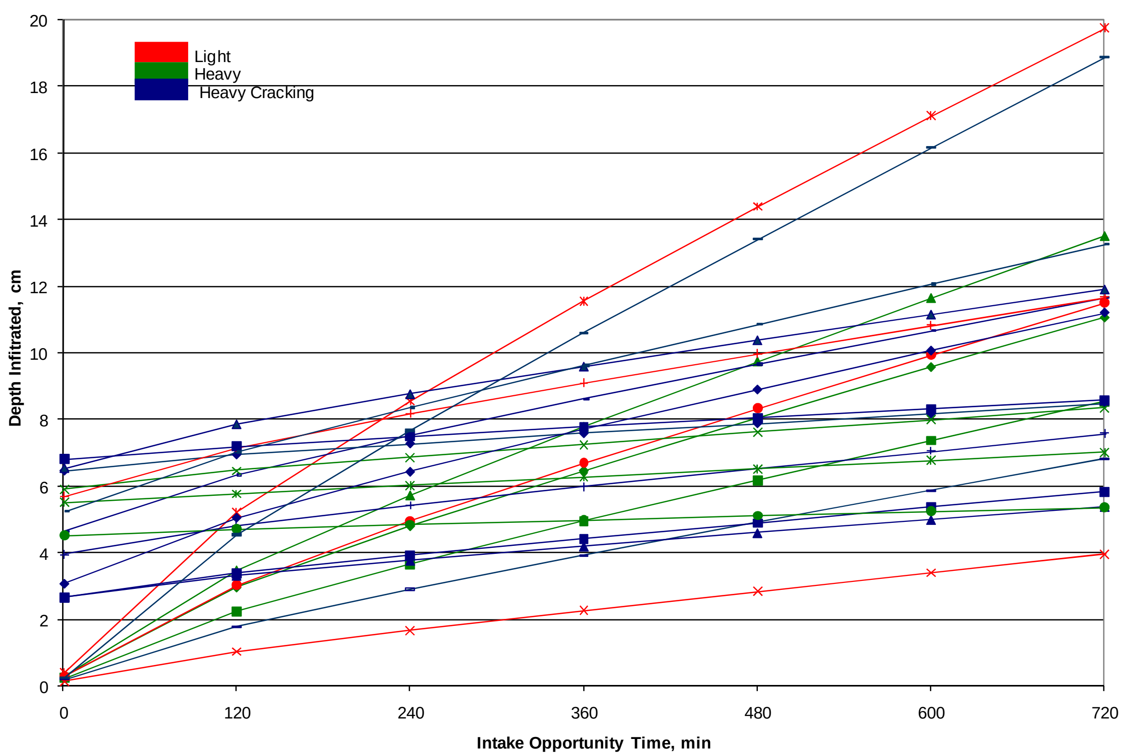


Figure 7b. Calibrated Intake Curves, Flat Events

Following model calibration, potential increases to irrigation performance were estimated for each event by running the SIRMOD model to maintain infiltration and distribution uniformity while increasing application efficiency. For irrigation scheduling, inflow rate was varied and cutoff times were maintained. For event management, both inflow rate and cutoff time were optimized. Application efficiency (AE) cumulative distributions were used as a surrogate for CUF in the SIRMOD analysis and plotted for the calibration and optimized data sets. The water-weighted average application efficiency over the course of a season, when calculated based on the soil moisture deficit prior to irrigation, is equivalent to the CUF. The optimized distributions were "detuned" (adjusted downwards) to account for difficulties in optimizing application efficiency over the course of an irrigation season for each irrigation event due to various uncertainties faced by growers in addition to field non-uniformity. The detuned distributions were used to develop the CUF shift parameters to estimate potential increases in performance Valley-wide (as described previously in Figure 3). The distributions of AE from the SIRMOD runs are shown in Figures 8a and 8b for row and flat events, respectively.

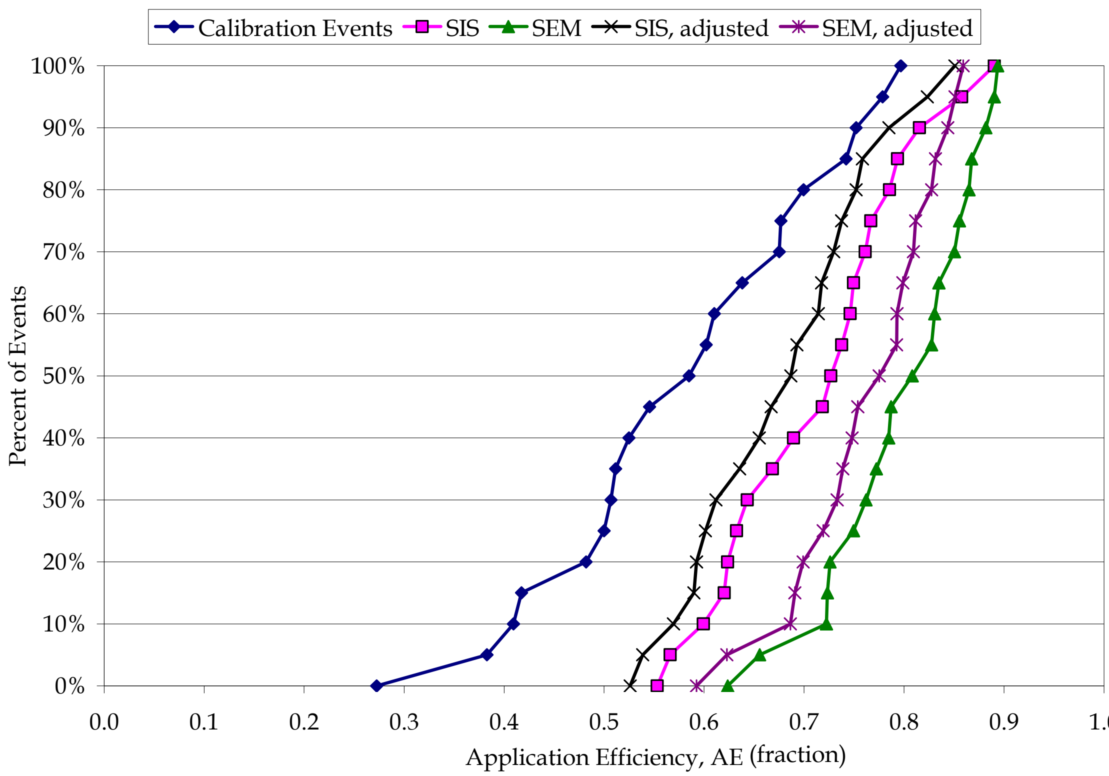


Figure 8a. Cumulative Distributions of Application Efficiency from SIRMOD, Row Irrigation Events

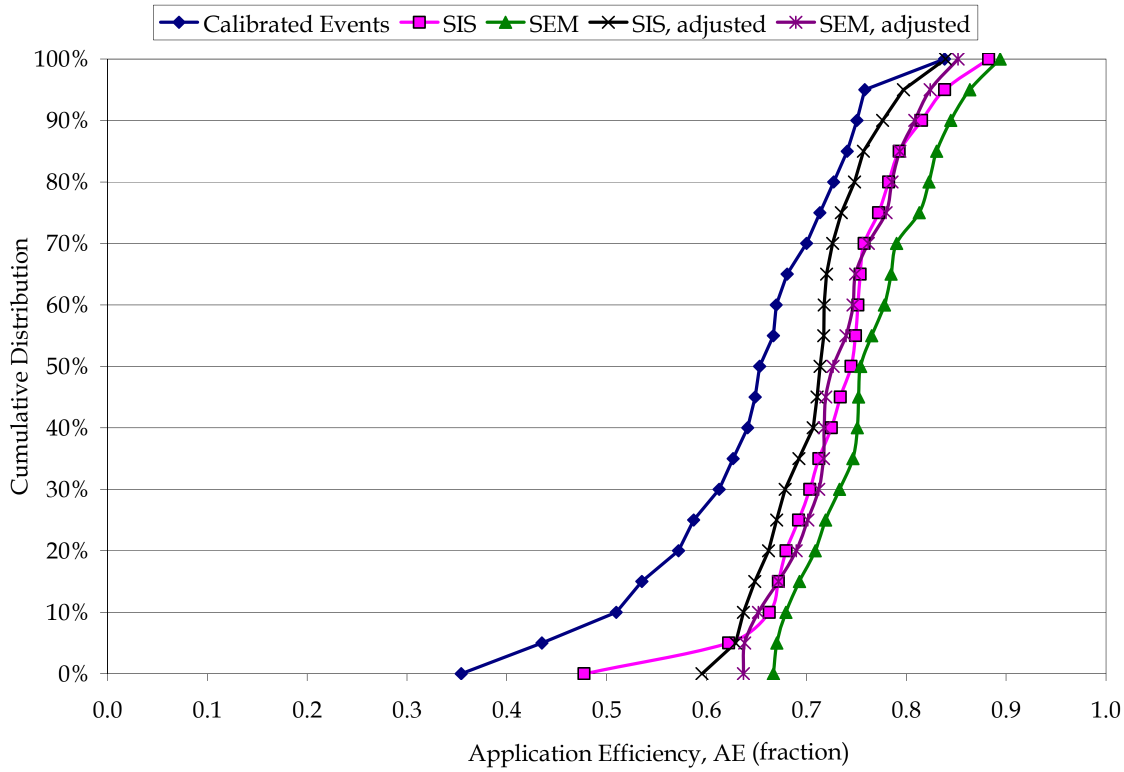


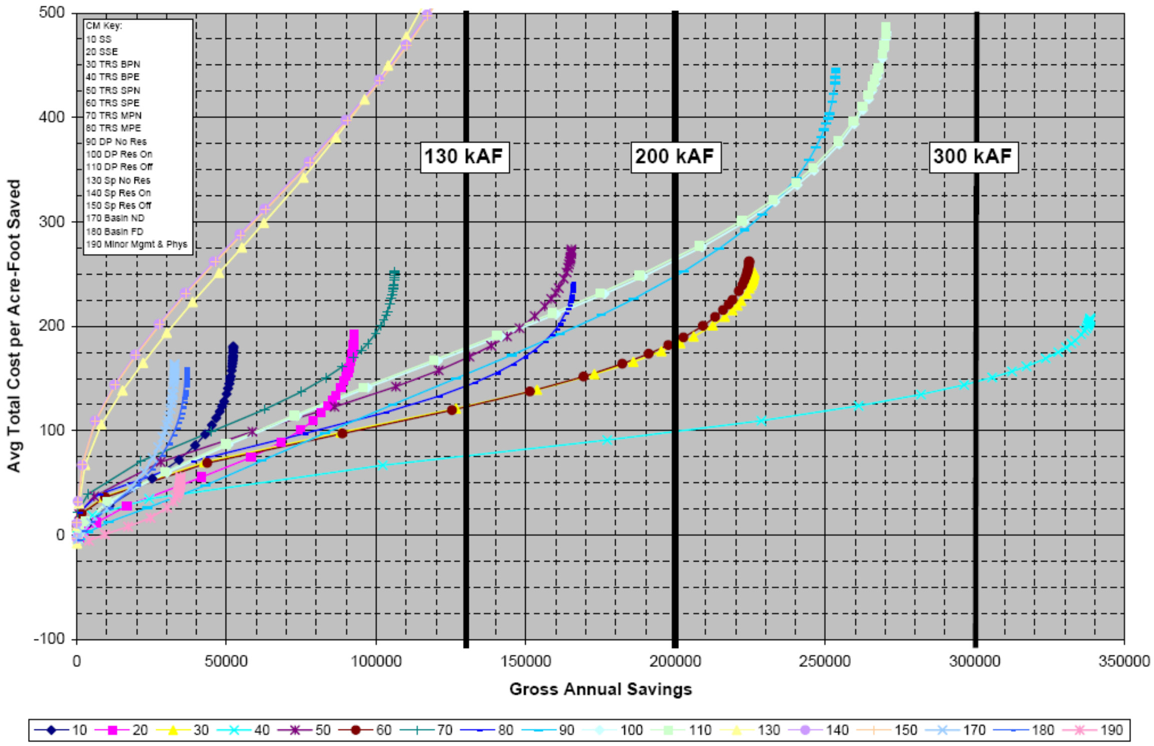
Figure 8b. Cumulative Distributions of Application Efficiency from SIRMOD, Flat Irrigation Events.

COMPARISON OF WATER SAVINGS AND IMPLEMENTATION COST ESTIMATES TO RESULTS FOR OTHER CONSERVATION MEASURES AND PROGRAMMATIC IMPLICATIONS

As described previously, water savings and implementation costs for all CMs evaluated were estimated for over 103,000 historical crop seasons. Typical ranges of water savings and implementation costs are shown in Table 3. Cumulative conservation and average implementation costs were plotted for each CM. The distributions are shown in Figure 9.

Table 3. Typical Savings and Costs by CM

Conservation Measure	Cost Range ($/ac-yr)	Delivered Water Reduction Range (ac-ft/ac-yr)
Irrigation Scheduling and Event Management	$ 35 to $ 135	0 to 0.5
Drip Irrigation	$ 395 to $ 625	0 to 1.7
Sprinkle Irrigation	$ 624 to $ 812	0 to 1.4
Tailwater Recovery Systems	$ 145 to $ 442	0 to 1.5
Level Basin Irrigation	$ 180 to $ 312	0 to 1.4



Series	CM Description	Series	CM Description	Series	CM Description
10	Scientific Irrigation Scheduling	70	TRS, Small Pond, Normal Delivery	140	Sprinkle, Reservoir on System
20	Scientific Event Management	80	TRS, Small Pond, Extended Delivery	150	Sprinkle, Reservoir off System
30	TRS, Big Pond, Normal Delivery	90	Drip, No Reservoir	170	Level Basin, Normal Delivery
40	TRS, Big Pond, Extended Delivery	100	Drip, Reservoir on System	180	Level Basin, Flexible Delivery
50	TRS, Medium Pond, Normal Delivery	110	Drip, Reservoir off System	190	Minor Management and Physical Improvements
60	TRS, Medium Pond, Extended Delivery	130	Sprinkle, No Reservoir		

Figure 9. Average Implementation Cost per Acre-Foot Conserved On-Farm.[7]

Based on the results, it is estimated that a total of approximately 50,000 acre-feet could be conserved annually via irrigation scheduling at an average implementation cost of $150 per acre-foot. Likewise, approximately 90,000 acre-feet could be conserved annually via event management at an average implementation cost of $175 per acre-foot.

In each case (irrigation scheduling and irrigation scheduling combined with event management), total conservation with full implementation fall short of the minimum on-farm conservation amount of 130,000 acre-feet. Based on the Definite Plan evaluation of distribution system conservation opportunities, it is estimated that approximately 200,000 acre-feet will need to be conserved on-farm. Thus, it appears that it will be necessary to implement physical improvements such as tailwater recovery systems and pressurized irrigation in addition to management-based conservation measures in order to achieve program goals.

[7] In Figure 9, series "10" represents irrigation scheduling and series "20" represents event management. Series 30 through 80 represent various tailwater recovery configurations. Series 90 through 110 represent various microirrigation configurations. Series 130 through 150 represent various sprinkle irrigation configurations. Series 170 and 180 represent level basin configurations. Series 190 represents minor management and physical improvements.

CONCLUSIONS

SIRMOD provides a valuable tool to evaluate potential reductions in on-farm losses through improved surface irrigation management. The application of SIRMOD as part of the Definite Plan provided insights into both the amount of reduction in on-farm losses that could be achieved across a range of fields and into how to achieve those reductions. Future applications of SIRMOD could be used to develop field-specific or more generalized guidelines for improved surface irrigation management tailored to Imperial Valley conditions.

This analysis demonstrates the utility of defining the Consumptive Use Fraction in order to estimate incremental increases in irrigation performance resulting from CM implementation. Parameterization of the increase in CUF for individual fields based on historical performance allows for understanding of the range of costs and delivered water reduction amounts within a population of similar fields.

A wealth of additional information describing SIRMOD and the Definite Plan is provided in the references listed below.

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A CONFLICT MANAGEMENT SUPPORT SYSTEM FOR WATER RESOURCES AND IRRIGATION PROJECTS IN EGYPT

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ABSTRACT

Contemporary water resources management is a combined process of sharing water and resolving conflicts among stakeholders. There are many challenges influencing water management in Egypt such as water shortage, mismatch between supply and demand, agricultural expansion, water pollution, stakeholders' participation, economic development, and legislative constraints. The key indicators or the water conflicts are related to a number of issues including water quantity, water quality, management of multiple use, political divisions, geopolitical setting, level of national development, hydro-political issue at stake and institutional control of water resources.

The focus of the paper is to demonstrate a comprehensive review of literature of conflict resolution process. The review tackled definition of traditional and recent conflict resolution approaches, water resources management and irrigation projects conflicts in Egypt, main functional activities for assisting the conflict resolution process as communication, problem formulation, data gathering and information generation, information sharing, and evaluation of consequences.

The paper proposed adaptation of a systemic approach to approach resolution of conflicts concerning water resources management and irrigation projects. This systematic approach should provide help to stakeholders to explore and resolve the underlying structural causes of conflict and offers a significant opportunity for its resolution. Furthermore, the paper presented an application of the proposed systemic approach on a specific water management conflict in Egypt.

SYSTEMIC APPROACH TO CONFLICT RESOLUTION

A conflict resolution systemic approach has at least three roles in illuminating grounds on which conflict resolution may proceed. First, scientific investigation defines the systems that are affected and their structure (components), indicating where there is an established or assumed relationship among the various components. Definition of the system structure is fundamental because often conflicts arise where it has been assumed that the impacts were not as far-reaching as demonstrated in practice. Second, a systemic approach helps to describe the characteristics of the various components, including the physical systems, the ecosystems, and affected social groups and organizations with their preferences and modes of action.

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To identify the components is to deal with their interactions as they are established. Third, a systemic approach offers the means of estimating the significance of impacts not only in terms of physical quantities but also in terms of the way in which they are perceived by the people and organizations affected.

Table 1. Traditional versus systems approaches to conflict

	Traditional Approach	*Systemic Approach*
Intention	Conflict resolution	Conflict resolution skill building
Time horizon	Short term	Long term
Point of application	After conflict becomes extreme	Before conflict becomes extreme
Stakeholder response	Defend position	Become reflective and open
Focus	Individual adversaries	System
Processing of complexity	Polarization	Powerful dialogue
Responsibility for conflict	Blaming of others	Own role in conflict

Table 1 presents some differences between traditional and systemic approaches in conflict resolution. A systemic approach is proposed as a powerful tool for deep inquiry and development of dialogues among stakeholders. Active participation of stakeholders and development of their skills to deal with conflicting situations is the driving force of a systemic approach.

A NEW FRAMEWORK FOR WATER CONFLICT RESOLUTION

The recent collapse of many trans-boundary negotiations discloses significant shortcomings in traditional approaches to resolution of trans-jurisdictional water conflicts involving multiple stakeholders. Without full acknowledgement of the broader external issues fueling the conflict and without collaboration by the parties to eliminate extraneous sources of intractability, the core dispute is unlikely to be correctly framed and the negotiations may be ill-informed as a consequence. Poor framing can prevent consensus on core objectives and constraints and misdirect the formulation, analysis and evaluation of water management alternatives. Consensus remains elusive, the diligent efforts of the parties notwithstanding.

The core of the traditional approaches were models for simulation of operational alternatives, which, while sophisticated, addressed primarily symptoms, e.g. flow deliveries, water consumption, reservoir operations, drought response, etc., as opposed to causes of the conflict. The conflict resolution approaches demonstrate that incomplete characterization of the parties, issues, social system, and processes framing the conflict contributes to the difficulty and expense of the core modeling, and more importantly makes disclosure of satisfactory solutions around which consensus can be fashioned unlikely.

Several ideas for improvement of the water conflict resolution framework and processes embodied in the wake of the failed trans-boundary and local Compact negotiations have recently been proposed by some of the participants and academicians involved. Notwithstanding the need and potential for improvements in core simulation models, it is highly likely that the trans-boundary and local negotiations failed primarily due to the inability of the parties to recognize the underlying premises of the disputes and external factors preventing consensus. In recent years, researchers and practitioners have identified common characteristics of intractable environmental and resource allocation conflicts with respect to the parties, issues, social system, and processes involved.

PILOT DEMONSTRATION OF NEW FRAMEWORK FOR WATER CONFLICT RESOLUTION (Abou Kebeer District)

The paper proposes to adopt a new framework for management of water conflicts. The procedure involves the following four steps:

- Identification of sources of intractability in the parties, issues, social system, and process
- Conflict re-framing to eliminate or minimize sources of intractability
- Consensus on core problem definition, core objectives and constraints
- Parameterization of satisfying core models, consensus on management alternative

The paper conceptually describes the processes of re-framing and consensus management pending proof-of-concept demonstration at a pilot level. An existing model that the MWRI use will be applied to analysis of the core problem. Potential sources of intractability will be identified, characterized and understood, and the issues re-framed accordingly to remove these obstacles to successful resolution. The proposed pilot demonstration for water conflict resolution framework will present a local level water conflict.

PILOT DEMONSTRATION OF WATER CONFLICT RESOLUTION FRAMEWORK

Since prior to the liberalization of agriculture, the Ministry of Water Resources & Irrigation (MWRI) has delivered water to farmers on the basis of indicative cropping patterns and calendars determined by the Ministry of Agricultural and Land Reclamation (MALR) . Water releases from the High Aswan Dam (HAD) are based on these "indicative" cropping patterns and calendars, which are often released months in advance of real planting dates. Frequently, they are not accurate representations of the actual crops grown. Liberalization and farmer free choice have resulted in much more uncertainty about actual irrigation water demands. Cases of significant "mismatch" have occurred. In some cases, large amounts of water (sometimes millions of cubic meters) were delivered but not used, while at other times water has not been available to farmers when needed, causing a reduction in agricultural production. The MWRI has identified several specific situations that give rise to mismatching, which can be grouped into three general categories:

1. *Under- or over-estimating crop water demands under free cropping choices*, including cropping patterns and calendars.
2. *System constraints*, such as canal capacity, system storage capacity, and lag time between water releases from HAD to the farm.
3. *External factors*, such as climatic change and unanticipated drainage water reuse.

Water shortfalls have resulted from lack of information about cropping patterns and calendars and from cropping pattern and calendar selections by farmers that were not consistent with the ability of the Nile system to deliver adequate supplies when needed. Information on crop selection and the dates of planting and harvesting is essential for good water management. However, there is no routine, accurate, and systematic transfer of this information from farmers or the MALR to the MWRI, nor is there an understanding of the system constraints on the part of the MALR and the farmers. Now, both Ministries are recognizing that matching real-time irrigation water demands with water deliveries is an important step toward an efficient, demand-driven irrigation system.

The water management conflict discussed in paper is selected to illustrate that such a situation occurs primarily as a result of the inefficient use of the available water supply and the over/under-application of water at the local level. Through a case study of one region the paper seeks to outline the causes and extent of wastage/inefficiencies in the distribution of irrigation water in rural Egypt. By studying water use as a simple supply/demand relationship, it may be possible to locate where wastage and inefficiency were occurring. This was seen to be primarily on the supply side, although the inflexibility of farmer demand was also seen to be a significant factor in the mismatch of supply and demand patterns.

Many meetings have been conducted during this study with local ministry staff and local water users and farmers to survey and discuss parties, issues, and the nature of the water conflict and conflict resolution mechanism.

Four steps are required, the first three of which frame the conflict and establish parameters of the core modeling. The Decision Support System (DSS) will be designed to operationalize groundbreaking work in understanding of intractable conflict, consensus measurement, and operational water management models.

Step 1: Sources of Intractability

The first step in the conflict resolution process involves characterization of the parties, issues, social system, and process to identify factors potentially fatal to negotiation and consensus. The following are among potential sources of intractability:

- **Parties**

Mapping parties that have a stake or in other words stakeholders is the first step towards conflict resolution. The stakeholders differ with the nature of the water conflict. Potential stakeholders involved in a water conflict related to water allocation at branch canal level can be presented as follows:

- Under-Secretary for Irrigation
- General-Director of Irrigation
- Irrigation Inspector
- District Engineer
- Behary
- Ministry of Agricultural and Land Reclamation – Department of Agriculture Extension Department - Ag. Cooperatives
- Ministry of Transportation –
- Ministry of Housing
- Complaints Administration
- Social Fund (government agency)
- Environmental NGOs
- Minister of Health – local health [e]

- Agricultural Departments
- Environment Ministry – Member of local council
- Local Contractor
- Local Councils
- Mayor
- Local Clerics
- farmers
- Irrigation Advisory Service
- Minister of Interior
- Landowners in Cairo
- Local politicians – People’s Assembly
- Landless laborers
- Mechanical & Electrical Department
- Maintenance Department
- Ministry of Industry

The above list of potential stakeholders is covering all groups that may have influences, interests, impacts in the subject conflict. For a specific canal the above list can be adjusted by adding or removing. For example, for a canal that have only agricultural demand many of the listed stakeholders should be removed and others will move from one category to another.

For allocating water for agricultural demand the following figure 1 represents the current structure and relationships of involved parties:

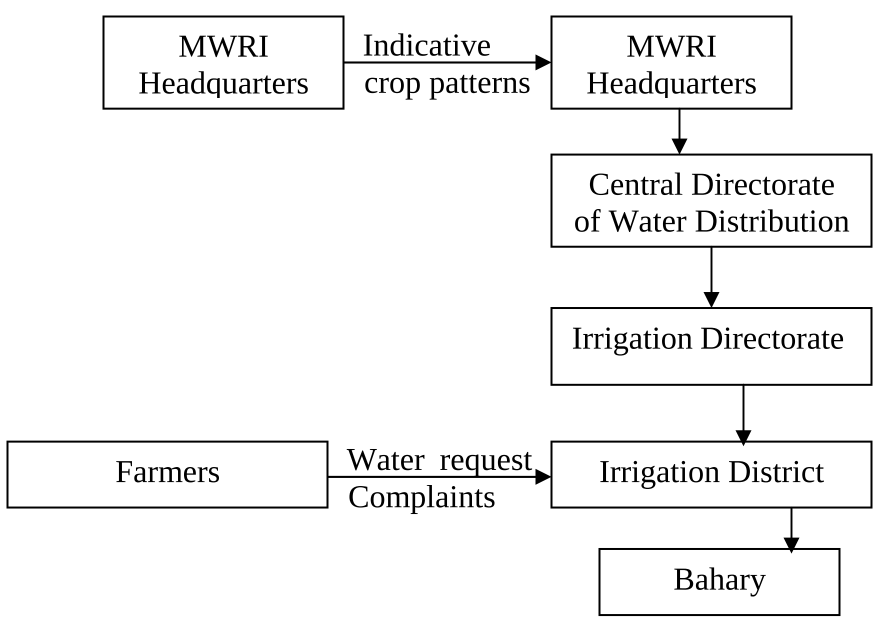

Figure 1. Water Allocation Data-Information-Decision Structure

Issues

Issues and disagreement rooted in ideology, culture, group membership, threats to public health and safety (non-negotiable) subjective values.

Conflict over irrigation water amongst farmers (internal) and between them and water authorities (external) exists in every community in Egypt. The nature of conflict varies widely between different areas (Districts, Directorates, Governorates).

The nature of conflict, as well as structures for resolution, has changed due to complex socio-economic and political factors. In general, the level, frequency and intensity of conflict is perceived to have increased since the 1970s. Distance from water source is the most important factor in determining the level of conflict. (Drainage reuse and water wells). All communities experience fluctuation in level of conflict in accordance with the season, with most conflicts arising in the summer.

Root causes of conflict

Real or perceived in-equality or unfairness in water distribution is at the heart of water conflict. Disputes over irrigation water are often entangled in complex layers of social, economic, political and technical factors between individual community members, families, and various other social and administrative groups. Also, agricultural driven conflicts provide an added dimension.

When it comes to external conflict between farmers and water authorities, the perception of the factors by the farmers is very different from that by the water authorities. Each tends to blame the other.

Farmers 'perception of causes

- Low water levels
- The capacity constraint of the irrigation canal system and its inability to absorb any additional allocations
- Poor maintenance of the canalization system
- Unlined watercourses and seepage.
- Insufficiency of water intakes.
- Poor management by incompetent and unaccountable water engineers
- Power and dominance by influential owners and owners of the new land areas
- Bribery and nepotism for the Baharys
- Brevity of irrigation time allowed per feddan
- Ineffectiveness of the fines imposed on unauthorized rice-growing
- Transgression by the fountainheads farmers against irrigation water

Water Authority's perception of causes (Districts, Directorates)

- Acts of transgression by the farmers
- High rate of water waste by farmers
- Lack of awareness amongst farmers about availability of water and allocation

systems and pollution control.
- Rapidly increasing rice-growing (illegal)
- Fragmentation of properties, increasing the number of stakeholders
- Change in farmers' life styles (rather watch satellite channels instead of irrigating their land during the night)
- Building bricks factories
- Waste disposal into canals and water contamination
- Increased unauthorized reclamation of land area, while the planned ones are not observing the required irrigation techniques. Use of unauthorized water-pumping machines
- Passage of watercourses into the inhabitants' blocks

Social System

The effects of conflict are extended to social, economic, environmental, political and other effects. These effects should be discussed and presented in a clear and transparent manner to all stakeholders.

- **Social effects**
- Affects the social cohesion and solidarity
- Weakens people's faith in traditional mechanisms and leadership structures
- Causes an increase in outward migration
- Increases polarization between 'old' and 'new' communities
- Causes Boys and girls to be withdrawn from schools to guard irrigation time
- The wife often end up at the receiving end when the conflict is amongst relatives

- **Economic effects**
- Low levels of productivity per Feddan and per drop of water as less land is cultivated
- Transgression adds to the ineffectiveness on the network and the cost of its maintenance
- Adds to the vulnerability of smaller farmers
- Farmers are less willing to physically or financially participate in the maintenance work
- The spread of fines and other conflict-related expenses as well as the need to borrow money to compensate for poor productivity results in an accumulation of debt
- A lot of time is wasted dealing with the effect of conflict

- **Environmental effects**
- Drives farmers to planting crops with higher yield e.g. rice
- Adds to the demand on water
- Adds to the level of water and environmental pollution
- The need by some to utilize drainage water affects the quality of land
- Conflict can occasionally cause land flooding

- **Political effects**
  - Increases farmers skepticism about the Government's ability to deliver on promises
  - Unresolved conflicts weakens decentralization and delays privatization
  - Weakens MWRI agenda on integrated water management
  - Disenfranchises people from political participation
  - Can be manipulated by some 'elites' to win local elections
  - Revives tribal and family allegiances

- **Other effects**
  - Procedural justice is not operating fairly to all
  - Retributive justice can result in imprisonment and therefore have negative effect on all concerned
  - Restorative justice is difficult to implement
  - Psychological pressure often reflected at family members back at home
  - General feel of insecurity
  - Wasted opportunities
  - Women end up taking up more responsibilities

Conflict Process Analysis

Initial demonstration of proof-of-concept would be performed through participant surveys designed to elicit information on the four source classes shown through step "1", to be evaluated and identified by conflict managers.

The prototype Water Resources Conflict Resolution - Decision Support System (WRCR-DSS) is envisioned to utilize expert systems and relational databases to assist in survey design and interpretation.

Step 2: Conflict Re-Framing

The second step in the conflict resolution process involves iterative re-framing and re-structuring of those aspects of the conflict potentially leading to intractability. The conflict managers should extend the spectrum of intractability sources depicted in step "1" to identify characteristics of resolvable conflicts.

The step of conversion of intractable conflict to tractable one requires that the parties, issues, social system and process be restructured to eliminate or minimize potential problem areas and avoid negotiations deadlocked by superfluous, ideological, religious or class differences extraneous to the set of core water management/allocation problems to be resolved.

Putting intractable conflicts on a path to successful resolution essentially involves organization of parties, reduction of the subjectivity, complexity and contentiousness of the issues, and provision of a robust framework for negotiations. Characteristics of potentially resolvable conflicts include the following:

- Parties – bounded (limited), well-organized
- Issues – consensual, distributional, quantitative; health and safety assured; objective values
- Social system – prescribed, legitimate, effective
- Conflict process – de-escalated, problem solving, discourse

Parties – bounded (limited), well-organized

After preparing the list of potential stakeholders according to category, the conflict manager will have the assignment of reviewing that list to identify each entry as being an "internal stakeholder" or an "external stakeholder". An internal stakeholder is a person or group within the MWRI, identified by an "i" following their name. An external stakeholder is any stakeholder not within MWRI, identified by an "e" following their name.

In our case potential stakeholders involved in a water conflict related to water allocation at branch canal level are restructured as follows:

Table 2. Restructured Stakeholders for Pilot conflict

Where: (i) = internal stakeholder , (e) = external stakeholder

CO-DECISION MAKER	♦ General-Director of Irrigation ♦ District Engineer ♦ Water Distribution General Directorate
TECHNICAL REVIEWERS	♦ Ministry of Agricultural and Land Reclamation – Ag. Departments, Ag. Cooperatives ♦ Ministry of Transportation – ♦ Ministry of Housing ○ Governorate – Authority of Sewage & Water Projects e ♦ Under-Secretary for Irrigation i ♦ Irrigation Inspector e
ACTIVE PARTICIPANTS	♦ Agricultural Departments ♦ Environment Ministry – Member of local council e ♦ EEAA e ♦ Local Contractor e ♦ Local Councils e ♦ Mayor e ♦ Irrigation Engineer e ♦ Local Clerics e ♦ Head-end farmer e ♦ Tail-end farmer e ♦ Irrigation Advisory Service e ♦ Educated/uneducated farmers e ♦ Male/female farmers e ♦ Tenant farmer e ♦ Behary e ♦ Minister of Interior ○ Special police for water courses e ○ Local police e ♦ Water Communication Unit i ♦ Complaints Administration i

COMMENTERS - External	♦ Member of Shoura Council [e] ♦ Social Fund (government agency) [e] ♦ Environmental NGOs [e] ♦ Sherook Local Community Development [e] ♦ Minister of Health – local health [e] inspector [e] ♦ Director of Agriculture – Local District Official [e] ♦ Department of Agriculture Extension Department [e] ♦ Landowners in Cairo [e] ♦ Local politicians – People's Assembly [e] ♦ Landless laborers [e]
COMMENTERS - Internal	♦ Mechanical & Electrical Department [i] ♦ Maintenance Department [i] ♦ Emergency Centers [i] ♦ Under-Secretary for Drainage [i]
SUSTAINABILITY – People or organizations who may help communicate or have an interest in sustainability.	♦ Minister of Education ○ Local school teachers [e] ○ Local school administrators [e] ♦ Farmer's wives [e] ♦ Press/media [e] ♦ Agricultural cooperatives [e] ♦ Youth Centers [e] ♦ Ministry of Industry [e]

Referring to internal and external stakeholders and categorizing the stakeholders into the presented categories in Table 2, is crucial in restructuring the involved parties. Downsizing this list of parties will be basic in achieving a reasonable set of parties that can be manageable and reach consensus.

The tractable conflict structure of parties for a canal water allocation conflict concerning agricultural demand will be as follows:

Table 3. Conflict restructures parties

Parties	Sub-Parties	Roles/Mission
Ministry of Water Resources and Irrigation	♦ General-Director of Irrigation ♦ Irrigation Inspector ♦ District Engineer ♦ Bahary ♦ Water Distribution General Directorate ♦ Irrigation Advisory Service	♦ Allocate water among Inspectorates and maintain canals to receive water ♦ Allocate water among districts ♦ Allocate water among branch canals ♦ Operate canals control structures ad report water levels ♦ Decide target water allocations ♦ Support establishment of WUOs and awareness raising

Parties	Sub-Parties	Roles/Mission
Ministry of Agriculture and Land Reclamation	♦ Ag. Departments, ♦ Ag. Cooperative	♦ Collect crop data for demand estimation
Water Users Organizations	♦ Head-end farmer ♦ Tail-end farmer ♦ Male/female farmers ♦ Tenant farmer	♦ Verify crop data ♦ Participate in water distribution down stream branch canal intake ♦ Decrease violations and over irrigation

Disputes may arise over the parties to be included in the negotiation and their roles, the issues to be addressed, the need for institutional reform and/or creation of new institutions such as Water Users Organizations. Also, establishment of legitimate authority for conflict management and plan implementation (i.e. an existing agency or a new committee), or the need for modification of the process itself may be needed.

Issues – consensual, distributional, quantitative

The general issues raised as objective causes of water conflict in step “1” should be analyzed and extended to more layers of secondary causes. The analysis of each of the five main objective water conflict cause is illustrated as follows:

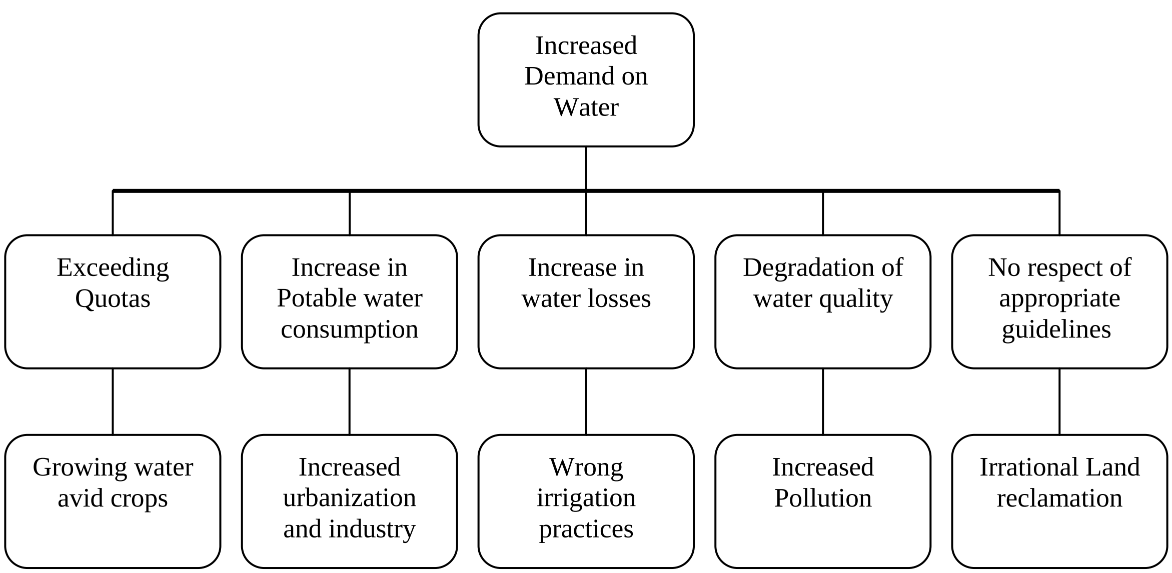

Figure 2. Causes of Increased demand on water

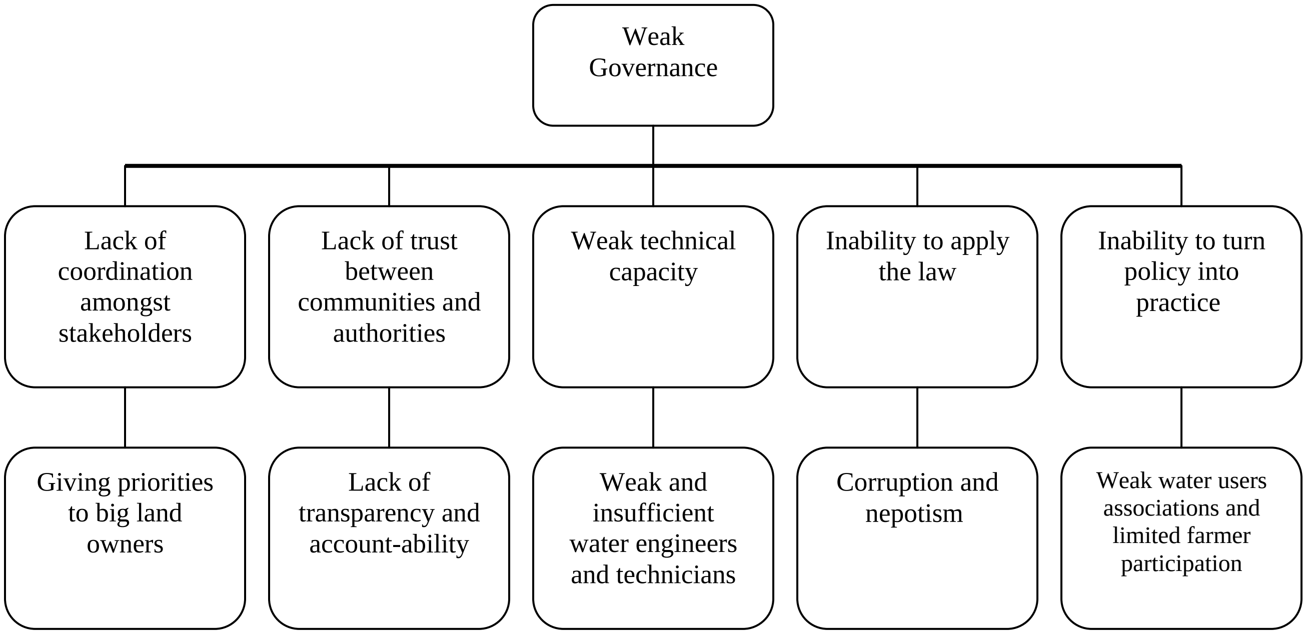

Figure 3. Cause of Weak Governance

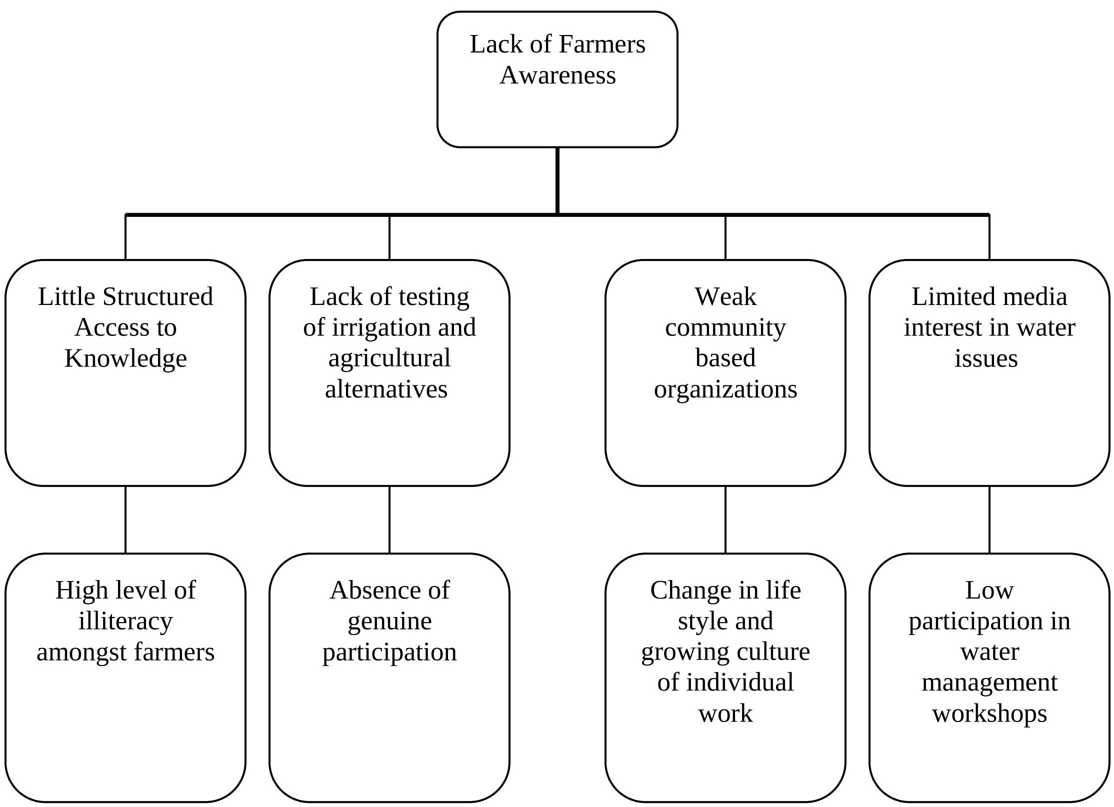

Figure 4. Causes of Lack of Farmers Awareness

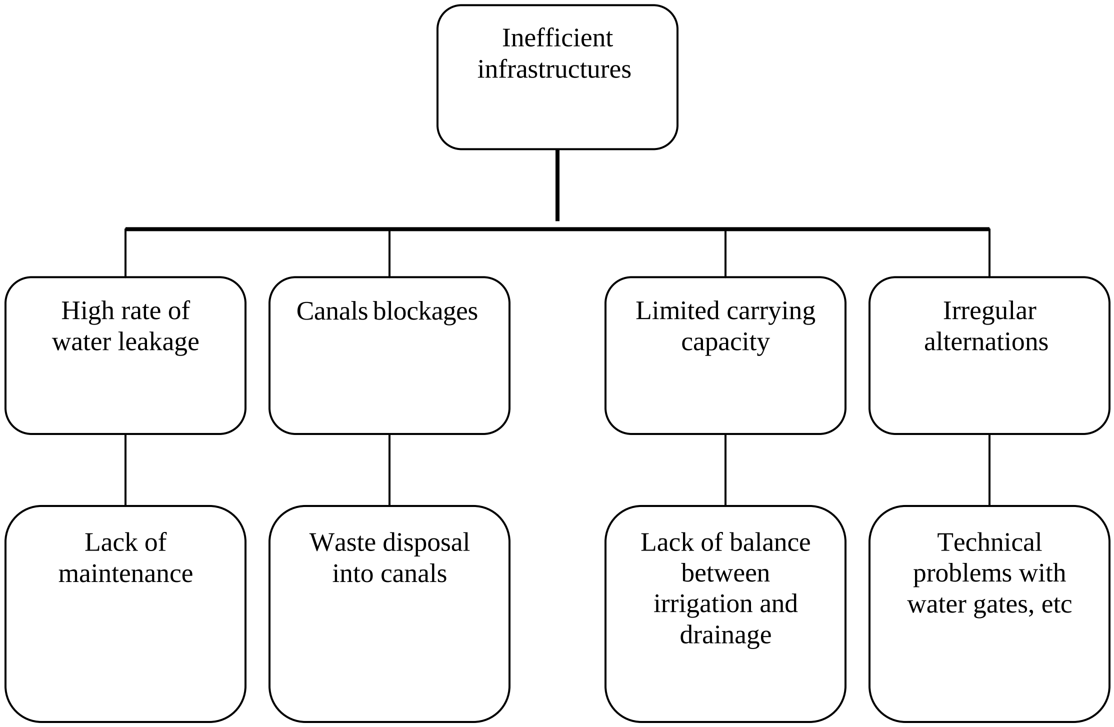

Figure 5. Cause of Inefficient Infrastructures

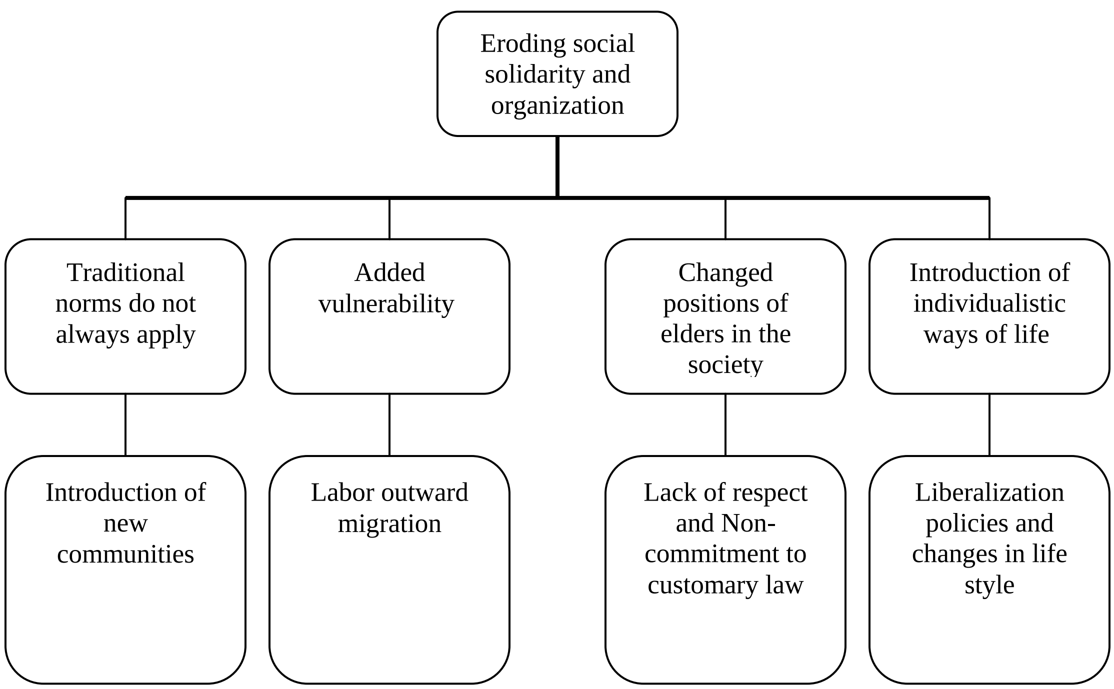

Figure 6. Causes of Eroding Social Solidarity and Organization

This analysis of issues and the breakdown of each issue into sub-issues is essential step in reframing the water conflict and in preparing for consensus among parties. Breaking down issues into sub-issues make it much easier and time-effective to achieve consensus among concerned parties and reach agreement among them on the root causes of the conflict.

What is needed afterwards is to limit the above discussed issues to issues that all parties can accept discussing and can reach consensus in the time being. For example, the two issues of inefficient water distribution practices and lack of farmers awareness can be the focus in the conflict resolution framework.

- **Social system – prescribed, legitimate, effective**

Presenting the social, economic, and legislative effects of water conflicts through step “1”, indicate that the problem of weak institutions and social structure have a big share in making the water conflict intractable. In step “2” the conflict manager should highlight these conditions to stakeholders and propose adjustment to be undertaken to help conversion of intractable conflict to a tractable one.

Institutional issues emerged throughout as being at the root of water-management problems. The collection, treatment, distribution, and disposal of water are generally over centralized, with little community participation. All too often, planners don't consult the people most directly involved in deciding how water should be distributed. Planners also fail to ensure that users, who are customarily expected to share in the maintenance of facilities, bear such responsibilities in proportion to their benefits from the system.

Particular emphasis should be made on the need to involve communities in the development, implementation, and management of water projects. Taking into considerations the fact that, too often, community participation is used by authorities to download the financial and labor costs of construction and maintenance of waterworks. It was pointed out that *community participation* was in itself misleading because it often did not take into account existing power structures within the community and frequently ignored the specific interests, roles, responsibilities, and needs of women in water management and utilization.

Over the next decades, the single most important consideration in water management will have to be that of institutional design — developing a set of rules that users, suppliers, and policymakers understand, agree upon, and are willing to follow.

- **Institutions**

The Ministry of Water Resources and Irrigation (MWRI) is in charge of water resources research, development and distribution, and undertakes the construction, operation and maintenance of the irrigation and drainage networks. Specifications and permits for groundwater well drilling are also the responsibility of MWRI.

The district is the smallest unit of the MWRI hierarchy responsible for all operational management aspects within its domain. Due to the different activities conducted by the MWRI at the district level, such as irrigation activities, drainage activities, groundwater activities, *etc*., the MWRI had established separate specific entities for these activities.

A civil engineer heads each district (irrigation or drainage) and is responsible for all operation and maintenance activities within the district. The irrigation district is supervised by an irrigation inspectorate. The Zifta inspectorate includes three irrigation districts. The Menoufia irrigation directorate consists of three inspectorates.

In case of water shortage, he asks the General Director to provide him additional water. In most decisions, the district engineer must refer to the general director. Regarding operation of canals, the district engineer is not involved in the determination of canal water requirements and scheduling of water releases (the annual water allocation plan). Regarding canal maintenance, the district engineer determines the maintenance requirements such as dredging, removal of aquatic weeds, rehabilitation of structures, etc.

The Ministry of Agriculture and Land Reclamation (MALR) is in charge of agricultural research and extension, land reclamation and agricultural, fisheries and animal wealth development.

- **Water management**

The Government has indicated its intent to shift emphasis from its role as the central (or sole) actor in developing and managing water supply systems, towards promoting participatory approaches in which water users will play an active role in the management of irrigation systems and cost sharing. Important institutional and legislative measures have been taken recently to promote the establishment of sustainable participatory irrigation management (PIM) associations. However, despite these measures, the development of water users' associations (WUAs) as effective partners in irrigation management remains at an early stage.

While most settlers recognize the importance of WUAs in the equitable distribution of available water, uneven water availability, either due to design shortcomings or to lax enforcement of rules against excess abstraction by head-tail water users, has acted as a disincentive to the successful operation of WUAs in many instances.

- **Finances**

The government invests considerable resources in the land-reclamation program. Investment is primarily in irrigation and drainage infrastructure, settlement construction, and provision of potable water, electricity and roads. Very little is invested in social services (education and health), and no investment is made in the provision of agricultural services (technology, water management and rural finance). Consequently, poor settlers face difficulties in settling and farming, and a considerable percentage move back to the old lands and abandon their new land farms. Both MWRI and MALR activities are considered public services and their water and land development projects are budgeted in the national economic and social development plan.

- **Policies and legislation**

The main water and irrigation strategy is concerned with the development and conservation of water resources. This is done through adopting water rotation for irrigation canals, limiting the rice growing area, lining irrigation canals in sandy areas and prohibiting surface irrigation in the new developed areas outside the Nile basin.

The legal basis for irrigation and drainage is set in Law No. 12/1984 and its supplementary Law No. 213/1994 which define the use and management of public and private sector irrigation and drainage systems including main canals, feeders and drains. The laws also provide legal directions for the operation and maintenance of public and private waterways and specify arrangements for cost recovery in irrigation and drainage networks.

- **Conflict process – de-escalated, problem solving, discourse**

In preparation to approach conflict resolution through this step the reframing process has produced the following:

- Limited number of parties,
- Limited number of issues identifying core issues,
- Collaboration, cooperation, and coordination framework

From this discussion it is apparent that characteristics of resolvable conflicts are generally mirror-opposites to those of intractable conflicts with respect to the parties, issues, social system and conflict processes.

The outcome of Step 2 is a conflict management framework designed to facilitate problem solving and consensus building. Careful review and analysis of the re-framed conflict management structure Step 1 will be necessary to ensure against magnification of minor obstacles or creation of new sources of intractability in Step 2.

Step 3: Consensus-Building

Once the major sources of intractability have been identified in Step 1 and eliminated (if not germane to the core water management problem) or re-framed to allow constructive problem solving to proceed in Step 2, consensus must be developed on the objectives and constraints of the core problem.

Consensus on Core Analysis Method

Surveying the stakeholders, they have looked to the mechanism that will be adapted to support water distribution conflict in terms of matching supply and demand at the irrigation district and branch canals. The procedure undertaken by both the MWRI and the MALR is as follows:

1. Cooperative links were forged between the MALR and MWRI at the governorate level and for the first time joint teams with continuous collaboration were established.
2. Agricultural data on cropping patterns and schedules are collected twice each month (at the first and middle of the month) by MALR hood extension agents who keep the land areas associated with each branch canal supplying irrigation water.
3. Two sets of data are collected: actual cropping pattern for the current half-month and expected cropping pattern for the next half-month.
4. The agricultural data are aggregated for all hoods and branch canals within the irrigation district boundaries and delivered to the MWRI district engineer.
5. A computer database program lessens the workload of processing agricultural data and improves accuracy of results.
6. Cropping patterns and schedules are forwarded from the district through appropriate levels to the Central Directorate for Water Distribution (CDWD) of the MWRI for scheduling water releases from the HAD.
7. There is a time lag between release of water from the HAD and its arrival at the point of use – about 14 days for the most remote part of the Delta. Delivery of irrigation water in the right amount at the right time depends mainly upon accurate data for the expected cropping pattern, *i.e.*, the forecast of future cropping patterns by the hood extension agent. It was agreed that the agricultural data would be available at the CDWD two weeks ahead of the arrival of water at its point of use.
8. The water allocation schedule is sent from the CDWD through appropriate levels to the district engineer.
9. Information on canal rotations and water availability goes from the district engineer to the agricultural administration and on to the farmers within the district.

Several activities should be carried out to support the MISD program development within the districts.

<u>MISD Program Elements</u>

- **Type of Data Transferred**

Cropping pattern and planting dates are the main factors for determining irrigation water needs of a given area. Cropping pattern, as used here, refers to the yearly sequence and spatial arrangement of crops or of crops and fallow on a given area. In the district, data are collected for each major crop, other crops, and fallow land. Fallow land, as used here, means agricultural land not being irrigated because of crop harvesting, land preparation for planting, or being in the time period between crops. Other crops are minor crops not occupying large areas and having similar water needs.

❖ Data Collection

For data collection, each month is divided into halves. Twice a month (at the first and middle), the MALR extension agent collects two sets of cropping data for his hood. One set is the actual cropping pattern for the present half-month period and the other set is the cropping pattern expected for the next half-month. For example, at the first of May, he collects the actual cropping pattern for the first half of May and the expected cropping pattern for the last half of May. At the middle of May, he collects the actual cropping pattern for the last half of May and the expected cropping pattern for the first half of June. The key to success of the program is the ability of the extension agent to determine, with precision sufficient for proper water delivery, the expected cropping pattern in the half-month period that starts two weeks in the future.

❖ Data Transfer

The agricultural data is available at the Central Directorate for Water Distribution, MWRI, two weeks ahead of the arrival of water at its point of use. This period was considered by MWRI to be enough to reschedule HAD water releases where released water takes about 10 days to reach Cairo, and to be available for distribution to the Delta region.

The MALR extension agent delivers the cropping data of his hood to the agricultural cooperative where the data are aggregated for all hoods of the cooperative. Then, the cooperative delivers the aggregated data to the director of agricultural administration who further aggregates data from all cooperatives on both branch canal and administration levels and delivers these data to the irrigation district engineer (MWRI) (Figure 7).

The irrigation district engineer receives the agricultural data and does the required processing and calculations of water requirements and canal rotations, *i.e.*, converts agricultural data into water demand data for his district.

The irrigation inspector aggregates the water demand data of all districts in the inspectorate. These data are successively passed through all levels of MWRI until they reach the Central Directorate for Water Distribution where the plan is developed for appropriate water releases from HAD to meet the water needs for the country. Adjustment of the water allocation plan might occur based on available water supply and operational conditions of barrages and main canals.

The water allocation plan set by the central level goes back through all levels to the irrigation districts. Finally, the water allocation plan, canal rotation, and other water information go from the MWRI irrigation district to both the BCWUAs and then to farmers, and to the MALR agricultural administrations where they are forwarded to the agricultural cooperatives, the agricultural extension agents, and again to the farmers. Consequently, farmers are aware of the available supply of irrigation water and canal water rotations.

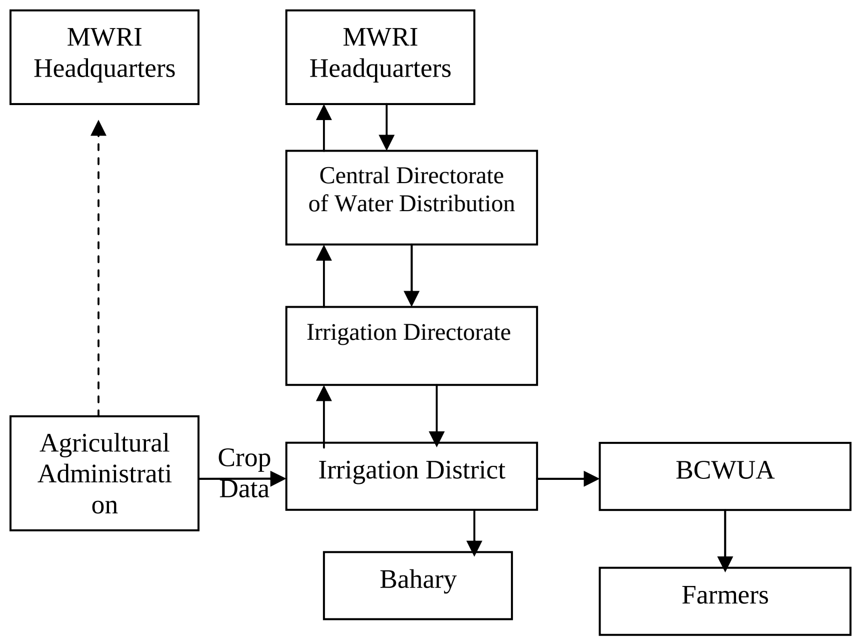

Figure 7. Re-Structured Water Allocation Data/Information Transfer

This procedure will be used as the model for conflict core analysis. In addition to the objectives and constraints, Step 3 should also produce agreement on the methods, models and data for the core analysis.

Should consensus on the objectives and constraints of the core analysis not be achieved, or new sources of intractability be disclosed in the process of consensus-building, it may be desirable or necessary to repeat Step 2.

Step 4: Core Analysis

Step 4 is focused on development and application of data and satisfying models rather than identification and framing of the core issues. The conflict resolution framework through this step will help to formation of consensus on a selected water allocation mechanism.

Step 4 involves the operational simulation of selected water allocation model, objectives, constraints, rules, priorities and model parameters around which consensus was achieved in Step 3.

The objective of this demonstration is to present MISD program as a tool for the MALR and MWRI to adopt a systematic, coordinated system of routine, real-time information transfer on actual irrigation water demands and supplies. Information on cropping intentions, particularly planting and harvesting dates, must be collected, organized and provided to MWRI personnel in sufficient time to permit the release of appropriate amounts of water from the HAD, taking into account the lag between release and delivery (which may be up to two weeks). Further, farmers and MALR personnel should be made aware of any expected shortfalls or problems in water supply in sufficient time to allow farmers to adjust. The most critical periods for this information exchange are those which involve land preparation and planting.

Collection of Information

The MALR and MWRI personnel at the district and directorate levels agree on the list of major crops for which crop area is needed in each irrigation district. All crops not on this list are included in the "other" category. Also, the total area of each Hood available for cropping is determined as well as the area served by each canal supplying water to the Hood. The gathering of crop areas then proceeds as follows:

- Twice each month (at the first and middle of the month), MALR Extension Hood observers determine the existing area (feddans) for each major crop, for all other crops as one category, and for fallow land (not irrigated) in their Hood.
- At the same time they determine existing crop areas, the Hood observers also determine the crop areas (feddans) expected for the next half-month period using the same categories, *i.e.*, each major crop, other, and fallow.
- Each Hood observer should ensure that the sum of feddans in all categories equals the total area available for cropping within the Hood.
- If their Hood is served by more than one canal, the observers keep the crop area grouped by the individual canal supplying water to each part of the Hood.

Transfer of Cropping Pattern Information

- Each Cooperative within the Agricultural Administration is responsible for getting the cropping pattern information from all Hoods within the Cooperative and delivering it to the Agricultural Administration.
- The Agricultural Administration enters the cropping pattern information for all Hoods into the computer database. The computer aggregates the crop area for all Hoods and branch canals within the irrigation district boundaries and produces a report that is delivered in electronic form to the MWRI district engineer either on diskette or as an email attachment.
- For the entire irrigation district, the report lists canal-by-canal the number of feddans of each major crop, other, and fallow, for both the current half-month period (existing) and the next half-month period (expected).

Irrigation District Use of Cropping Pattern Information

The MWRI district engineer can use the cropping pattern information for the existing period to manage the water already being received by the district. The "expected" cropping pattern information is used to determine the water that must be released for delivery to the district in the next half month. The irrigation district engineer enters the electronic report of cropping pattern information received from MALR into a computer program to calculate:

- for existing crops (current half month),
  - the needed water deliveries for each branch canal within the district
  - the total needed water delivery for the district
- for the expected crops (next half month),
  - the needed water deliveries for each branch canal within the district
  - the total needed water delivery for the district.

Water-Monitoring Program in the pilot district

A water-monitoring program was initiated in the pilot irrigation district to determine water supplied to each irrigation district. This information helps in assessing the extent of mismatch between irrigation supplies and demands in this pilot district. Water flow data were summarized to give daily flow in m^3. It is recommended that the MWRI continue water flow measurements as a regular part of their MISD program.

Canal System in the pilot district

The Abou Kebir Irrigation District gets its water quota from the second order Bahr Mouis Canal and the third order Bahr Abou Elakhdar Canal. These two canals take water from the Tawfiki Rayah Canal that gets water from the Nile River just upstream of the Delta Barrage. There are five branch canals that take water from the Bahr Mouis to irrigate the district in addition to another branch canal that takes water from Bahr Abou Elakhdar Canal. Smaller canals branch from these six branch canals.

Table 4 shows the canal command areas compared to those calculated from the agricultural data using hood areas. There is an obvious discrepancy between estimates of command area as reported by the two ministries MALR and MWRI. It was recommended that the local personnel work with maps of scale 1:2500 in order to resolve this issue and agree upon the areas irrigated from each branch canal.

Table 4. Sample Comparison Between Canal Command Area Estimates of MWRI and MALR in Abou Kebir Irrigation District.

No.	Canal	Branching from	Order	Total Canal Area (fed)	(1) Direct Irrig. Area (fed)	(2) Direct Irrig. Area (fed)	Difference [(1)-(2)] (fed)
1	G.R. Elsady	Bahr Muis	3	2000	960	1240	-280
2	Albedea	G.R. Elsady	4	750	750	390	360
3	G.L.Elsady	Bahr Muis	3	3300	3300	1715	1585
4	Kafer.Alnasede	G.R. Elsady	4	290	290	540	-250
5	Albouhia	Elsady	4	1000	1000	1085	-85
6	G.Abou Kbeer	Elsady	4	2000	2000	1036	964
7	Elmouralia	Elsady	4	6550	5275	3124	2151
8	Elserou	Elsady	4	4600	1380	3045	-1665
9	Elmanshar	Elsady	4	1500	1500	1327	173
10	Elmashala	Elsady	4	3650	2250	2324	-74
11	Awlad Mousa	Elsady	4	2600	2600	2462	138
12	Elraml	Elsady	4	2150	1050	588	462
13	Elraml Diversion	Elsady	4	300	300	100	200
14	Elmasaida	Elsady	4	1000	900	309	591
15	Manzal Maimoon	Elsady	4	2400	2400	1831	569
16	Elsady D.S.	Bahr Fakous	4	1400	1400	90	1310
17	Elahraz	Elsady	4	1750	1750	655	1095

(1) Estimate of irrigated area as estimated by MWRI.
(2) Estimate of irrigated area as estimated by MALR.

Water Distribution System in the pilot District

The canals shown in Table 5 deliver water to the district based upon a two-turn rotation system during the rice season and a three-turn rotation system for the rest of the year.

Water is allocated to branch canals by maintaining target water surface levels instead of by water volumes. The gatekeepers use marble gauges to monitor water levels. However, telemetry stations are installed on the Elsady head gate and the cross regulator in the middle of canal.

Table 5. Sample Seasonal Dates of On-period of Canal Rotation System in Abou Kebir Irrigation District

Turn **A**		Turn **B**		Turn **C**		Turn **E**		Turn **F**	
From	To	From	To	From	To	From	To	From	To
11-Feb-00	16-Feb-00	16-Jan-00	21-Jan-00	21-Feb-00	26-Feb-00				
26-Feb-00	2-Mar-00	31-Jan-00	5-Feb-00	7-Mar-00	12-Mar-00				
12-Mar-00	17-Mar-00	15-Feb-00	20-Feb-00	22-Mar-00	27-Mar-00				
27-Mar-00	1-Apr-00	1-Mar-00	6-Mar-00	6-Apr-00	11-Apr-00				
11-Apr-00	16-Apr-00	16-Mar-00	21-Mar-00	21-Apr-00	26-Apr-00				
26-Apr-00	1-May-00	31-Mar-00	5-Apr-00	6-May-00	11-May-00				
11-May-00	16-May-00	15-Apr-00	20-Apr-00	21-May-00	26-May-00				
						11-May-00	15-May-00	16-May-00	20-May-00
						21-May-00	25-May-00	26-May-00	30-May-00
						31-May-00	4-Jun-00	5-Jun-00	9-Jun-00
						10-Jun-00	14-Jun-00	15-Jun-00	19-Jun-00
						20-Jun-00	24-Jun-00	25-Jun-00	29-Jun-00
						30-Jun-00	4-Jul-00	5-Jul-00	9-Jul-00

Crop Water Needs

A key component of the MISD program is for the irrigation district engineer to use the cropping pattern information transferred from the MALR to calculate the real-time crop water needs. It was recognized that better tools would improve the district engineer's ability to make these calculations accurately and quickly and would assure that good water needs information was transferred to the CDWD of MWRI for scheduling water releases from the HAD.

Use of MISD Tool in Pilot District

Calculations of crop water needs were made for the whole period of cropping pattern and water delivery information collected during the period from March 1, 2000 through September 30, 2001. The results of the spreadsheet calculations and comparisons for pilot district are presented in the hereafter (figure 8). For each half-month period, results are tabulated for the crop water needs of the current crops "existing" in the district and for those crops projected as "expected" from the previous half month. Also tabulated are volumes of water delivered to the district. Both the required and delivered water are expressed as average daily values over the half-month period for the total district (in million m^3/day) and on a per feddan basis (in m^3/(day feddan)).

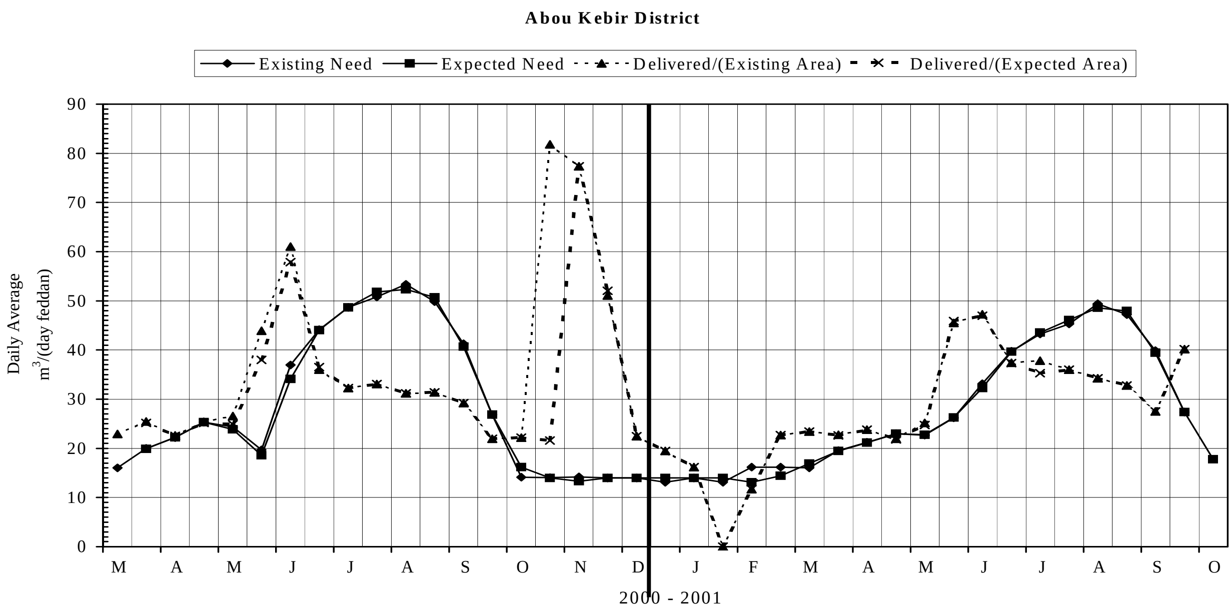

Figure 8. Average biweekly crop water needs and water delivered to the Abou Kebir District expressed as m^3/ day per feddan of crop area from March 1, 2000 through October 15, 2001.

Figure 8 shows the water delivered to the Abou Kebir District compared to the calculated water needs for March 2000 – September 2001, as daily values averaged over the half-month period expressed in million m^3/day. The curve labeled "existing" need shows the water needed by the existing or current crops for the particular half month. The "expected" need for the particular half month is the water needed by the crops calculated from cropping patterns that were forecast from the previous half-month.

Some significant observations can be made from Figure 8 . First, note that, in general, there are relatively small differences between the existing need and the expected need curves and considerably more differences between either of these two curves and the water delivered curve. Thus, the MISD process of forecasting the cropping pattern expected in the next half month appears adequate for improving the match of irrigation supplies and demands. In fact, considerable improvement can be made by delivering water closer to the real-time crop needs. Second, there is generally over-delivery of irrigation water in the winter and in the transition periods between winter and summer crops and between summer and winter crops and under-delivery during the peak of the summer season except for the Upper Egypt districts. Third, there appears to be a trend toward delivering water in the pilot district closer to crop needs in 2001 than in 2000. This is believed to be true because the district personnel were trying very hard to do the best they could with the tools and information available to them. Keeping in mind that the Excel spreadsheet for calculating real-time water needs from the cropping pattern information was not put into the pilot district until September 2001.

Use of the new tool for calculating real-time crop water needs from cropping pattern information is expected to significantly reduce mismatch in the future implementation of the MISD policy

Sharing and exchanging these results after analysis with the concerned stakeholders should resolve the conflict in terms of that claimed shortage by the farmers is in real practice over application and wastage of water. Actually, a lot of water should be saved based on the existence of a reliable data exchange and information transfer between those stakeholders but at the appropriate level. A consensus should be achieved amongst concerned stakeholders about the core conflict and core conflict resolution framework and management mechanism.

If consensus cannot be achieved on management mechanism, the model may be re-run with new rules, priorities and parameters. Alternatively if the analysis discloses larger problems in conflict framing, weaknesses in the chosen objectives and constraints, or the need for application of other methodologies and models, repeat of Step 3 may be desirable.

Because of the expense of DSS development and testing in connection with Steps 1 – 3, a prototypical application is desirable to demonstrate the feasibility of the approach. A proof of concept application to a bounded (not overly-complex) problem, with the parties limited and one or two sources of intractability present, could be performed relatively quickly and inexpensively. Steps 1 – 3 could be performed ‘manually’ by a panel of experts, and existing traditional models and data could be applied to Step 4. The negotiations could be conducted in ‘focus group’ format, and the outcome would be non-binding on the parties.

CONCLUSION

The paper proposed synthesizes widely-recognized elements of successful conflict resolution to adopt a new framework for management of water conflicts. The procedure involves the following four steps:

- Identification of sources of intractability in the parties, issues, social system, and process
- Conflict re-framing to eliminate or minimize sources of intractability
- Consensus on core problem definition, core objectives and constraints
- Parameterization of satisfying core models, consensus on management alternative

The paper demonstrated a pilot application of the proposed water conflict resolution framework. The pilot tackled the water allocation conflict at the local level.

RECOMMENDATIONS

- The MWRI may need to institutionalize the water conflict resolution in its regional, inter-ministerial, and local level.

- The MWRI may need to build the capacity of its engineers at different level on water conflict and resolution mechanisms and skills. If not, the ministry may need to adopt new profession in this field.
- Also, it is important to initiate a knowledgebase for water conflicts at different levels in Egypt by initiatives from the MWRI.
- There is an anticipation that a computer-aided decision support system may be developed to be working on different levels to improve prospects for non-judicial resolution of environmental and resource allocation conflicts. This proposal is especially well-suited to statewide water planning, interstate water allocation, water resource development, inter-basin transfers, and related issues involving multiple jurisdictions and competing uses of water. The approach can also be adapted to a wide variety of developmental, regulatory, and other issues related to management of private and common-property resources by regulatory agencies, local governments, planning agencies, developers, utilities and manufacturers.

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WATER QUALITY AWARENESS AND MANAGEMENT AT DISTRICT LEVEL

Dr. Moamen El-Sharkawy[1]

ABSTRACT

Experiences establishing Water User Associations (WUAs) in Egypt have been carried out for the past 15 years, with increasingly promising results. Most of these activities have been pilot projects aiming to demonstrate the benefits and sustainability of WUAs. Since 2003, the Ministry of Water Resources and Irrigation (MWRI) has adopted as policy the large-scale development of Branch Canal WUAs. About 600 branch canal WUAs (BCWUAs) have since been established.

BCWUAs are being formed to promote participatory approaches in all aspects of water management. Under the MWRI Integrated Water Management Program (IWMP) implemented through the Integrated Water Management Unit (IWMU), 27 IWMDs were formed in four governorates: Aswan, Qena, Sharkiya and Gharbiya. The 27 Integrated Water Management Districts include about 600 BCWUAs covering 15% of Egypt's irrigated area and involving half a million farmers, water users and residents. The BCWUAs empower water users to better assess their needs and priorities, solve local scale conflicts and issues on their own, and partner with MWRI staff to solve larger-scale issues.

Under the IWMP, the ministry IWMU has supported the IWMDs in establishment and activation of BCWUAs through technical assistance, capacity building based on both class-room and on the job training. This support was mainly focusing on the IWMD and Directorate staff with the objective of that they will extend this support for providing the needed orientation and capacity building for the established BCWUAs in order to motivate and activate their participation with the IWMDs.

A different approach has been developed and implemented, emphasizing the direct involvement of MWRI field staff and a partnership between water users and MWRI managers, to increase awareness and capacity building concerning water quality improvement at the local level. This paper argues that the approach of employing IWMDs and BCWUAs users, and empowering them to take over the water quality and environmental improvement initiatives at local level, can be adapted and succeeded to increase awareness and improve water quality within the Egyptian context.

INTRODUCTION

Experiences establishing WUAs in Egypt have been carried out for the past 15 years, with increasingly promising results. The first attempts were led by the MWRI in the late 80s early 90s under the USAID funded Egypt Water Use and Management (EWUP) and the Irrigation Management Systems (IMS) projects. The USAID and World Bank-funded

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Irrigation Improvement Projects (IIP) went along by establishing mesqa[2] WUAs, while the Fayum Water Management Project (FWMP) formed branch canal-level Water Boards. Recently the Water Boards Project has initiated the establishment of District Water Boards.

Apart from the IIP projects, where WUA establishment mostly supports mesqa structural improvement, the other projects aimed to prove the feasibility and sustainability of WUAs. They consequently focused on limited numbers of associations, and used a resource-intensive formation process, with implementation and monitoring done at central level. They were able to sensitize water users and MWRI staff to the benefits of water user participation.

Starting in 2003, the MWRI has initiated the large-scale formation of BCWUAs implemented through the Integrated Water Management Unit (IWMU), starting first with 94 of them in 4 pilot irrigation districts, and now with several hundreds of them over five entire irrigation directorates. In order to implement a large scale environmental and water quality awareness and improvement program without too time and resource-intensive approaches an innovative approach that relies and employs IWMD-BCWUA structure has been developed and implemented, as presented hereafter.

KEY PRINCIPLES FOR LARGE-SCALE DEVELOPMENT OF BCWUAS

Large-scale development of water users involvement in water management implies rationalizing the BCWUA formation process, achieving concrete results and getting tangible benefits for water users, and also accepting that not all associations will achieve same level of success (some may be inactive or inefficient because of pre-existing community conflicts, lack of willingness, focus on other -not water related- issues, etc.).

Over the past two years, the MWRI has led large-scale formation of BCWUAs under its integrated water management program.

A preliminary step was to simplify the structure of the MWRI by establishing Integrated Water Management Districts (IWMDs) as sole local delegations (thus merging pre-existing irrigation and drainage districts). Then the established IWMDs will promote water users involvement through establishing water users' associations at the branch canal level so called BCWUAs (figure 1) adapting the following key principles:

- Increasing awareness that BCWUAs are an opportunity with clear benefits for motivated and determined MWRI staff and water users;
- Building the capacity of MWRI staff, chiefly at district level, to support BCWUA development, now and in the future;
- Providing a streamlined clear process for forming BCWUA;
- Empowering IWMDs to directly form BCWUAs, since this:

[2] Mesqas are tertiary level canals, privately owned and serving 50-300 feddans/acres through marwas (plot ditches). They are supplied by state-owned branch canals (secondary canals serving 500-5000+ fedddans/acres).

  - Promotes a direct partnership between BCWUAs and IWMDs (with IWMDs as a "single window" contact for water users to provide and receive information, express needs and priorities);
  - Reinforces the IWMD as sole MWRI agency at district level; IWMDs represent a unique venue to coordinate all water management activities and implement water projects, thus resulting in more appropriate and timely decision-making, more sustainable implementation and significant economies of scale;
  - Ensures sustainability (after project ends) by building the capacity of IWMD staff;
  - Reduces the cost of forming BCWUAs over all of Egypt by using existing local staff instead of using a specific implementing entity.
- Identifying clear benefits for both water users and IWMD staff; and
- Emphasizing the fact that BCWUAs are complementing the role of IWMD staff, not replacing it.
- Women should be given equal opportunity through this process. It is absolutely essential that female water users participate in the election as voters and candidates and participate as effective actors specifically in water quality issues.

The main strength of adapting these principles is to focus on actual activities and outputs to ensure that water issues are tackled and tangible benefits achieved, in terms of improved allocation of water resources and O&M funds, better resolution of water disputes, etc. This is eventually what builds the credibility and sustainability of BCWUAs (as opposed to optimal administrative and organizational procedures, which can be improved over time).

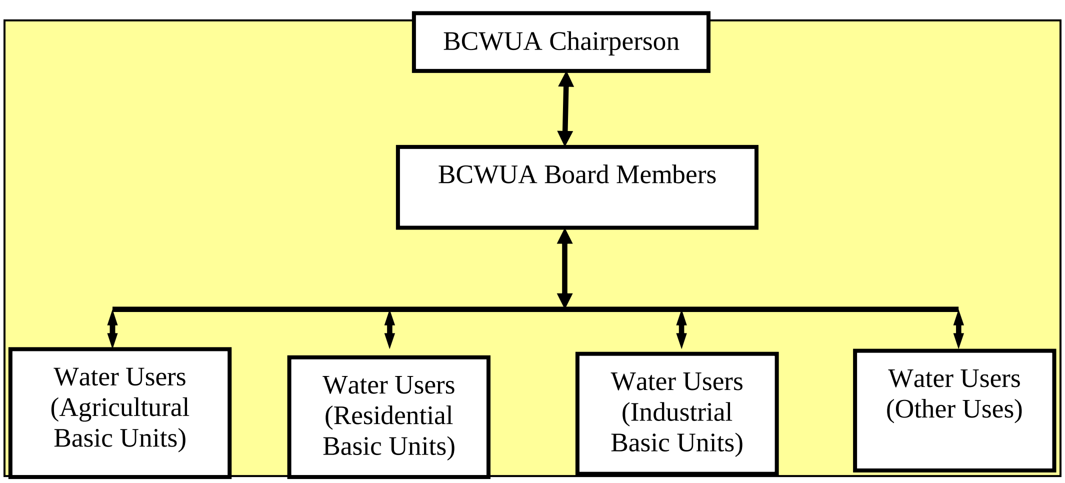

Figure 1. An Organizational Structure of a Typical BCWUA

PROCESS OVERVIEW

The BCWUA formation process involves five main steps:

- Introduction/Orientation: MWRI officers (especially IWMD managers) get acquainted with the BCWUA formation process, and a Water Advisory (WA) Team is selected and assigned in each IWMD;
- Preparation: geographical and social data is collected to identify where BCWUAs will be formed and to identify key water users; BCWUAs are delineated through canal grouping;
- Establishment: Key water users are informed about BCWUAs, sensitized to the benefits and convened to elect Board members and a chairperson; these representatives are acknowledged through a MWRI decree and invited to sign a Memorandum of Understanding (MOU) with the MWRI;
- Activation: BCWUA Boards prepare their own Internal Regulations, and collaborate with IWMD staff to identify key water issues, assess solutions and define actions and activities to be implemented; and
- Participatory Water Management: BCWUAs get involved in activities under four themes: water distribution, maintenance of waterways and structures, water quality, and communications and administration.

The four PWM themes cover most of the basic water management activities at district-level. Each activity should produce a specific output. In terms of the water quality management activities the following present each activity and corresponding output:

Topic		Activities	Outputs
Water Quality	1	Activities to manage liquid waste disposal	Waste management activities implemented (through Action Plan)
	2	Activities to manage solid waste disposal	
	3	Awareness activities regarding pollution	Awareness meetings/actions

These activities are implemented under the same overall approach that heavily relies on IWMD staff to support and engage BCWUAs. To that end and to nurture the IWMD-BCWUA partnership, benefits for both sides have been identified for each activity:

Topic	Activities	Benefits to IWMD/MWRI	Benefits to WUs
Water Quality			
	Activities to manage liquid waste disposal	Complements MWRI awareness activities, improves water quality	Improves water quality, environment, health
	Activities to manage solid waste disposal		
	Awareness activities regarding pollution		

Beyond building the credibility of the practice of water user participation, the objective is also to encourage a feeling of stewardship among water users so that they evolve from being passive requesters/beneficiaries to becoming responsible actors.

WATER QUALITY AWARENESS AND MANAGEMENT PARTICIPATORY FRAMEWORK

As presented, once the initial step was implemented establishing IWMDs, within less than 6 months, 20 to 35 BCWUAs were then formed in each IWMD.

After these BCWUAs signed Memorandum of Understanding (MOUs) with the MWRI, and have approved Internal Regulations, they started participating in water management activities. In order to be able to participate effectively, the BCWUAs members were oriented and trained by the IWMD staff. Concerning water quality management three major activities (as mentioned above) were initiated.

Activities To Manage Liquid Waste Disposal

Wastewater is one of the main sources of pollution in the irrigation and drainage systems in Egypt. Most rural areas dispose raw sewage water by dumping it into canals and drains. Sewage water also, seeps from septic tanks into the shallow groundwater aquifer. The problem poses serious consequences for hygiene standards through the country while increasing health hazards, soil deterioration, and degradation of agricultural production quantity and quality.

Figure 2. Liquid Waste Disposal in a Canal

Most of waterways that passes through inhabited and residential areas are vulnerable to sewage water dumping and pollution. As costs of constructing central wastewater treatment facilities and establishing sewage collection networks are usually high, Egypt is searching for practical solutions that can be financed and managed at the local level.

The activities initiated through the IWMDs and BCWUAs are:

1. encouraging water users to participate in solving their wastewater disposal problem,
2. introducing low-cost wastewater treatment techniques.

A wide variety of treatment technologies and methods of implementation have been developed to meet the various treatment requirements and constraints. These range in complexity from the simple pit privy or septic tank/leaching field system for small domestic applications to the technically more sophisticated packaged systems such as the Rotating Biological Contactor (RBC), Sequencing Batch Reactor (SBR) or Extended Aeration Plants (EA) designed for higher flows, wastewater strengths or more demanding discharge requirements. Each of these systems has a specific application or niche within the wastewater treatment field.

The focus of BCWUAs will be low cost/low technology methods for wastewater treatment. The focus will be on systems suitable for daily flows in the 5 to 50 m^3/day (and larger) range. A variety of applications will be considered including multiple family domestic, institutional (ie. schools), commercial (ie. retail, restaurant) and industrial.

By comparison with the technically sophisticated systems discussed above, low technology systems are simple in concept, design and operation. In most cases, the only operating component is a simple effluent pump. If required energy requirements can be met from solar power cell/battery combinations. In certain circumstances, systems can be setup to run entirely on gravity. Once established, ongoing operational and maintenance requirements are minimal. There is no requirement for ongoing balancing or chemical adjustment. High level training of operators is not required.

The main role of the MWRI IWMDs in this regard is to raise awareness and educate BCWUAs members about health and environmental implications of dumping raw wastewater into irrigation systems. Respectively, the role of BCWUAs members is to first, extend dissemination of this awareness and education to all stakeholders and water users in their areas. Second, the BCWUAs should play a key role in adopting low-cost wastewater treatment techniques through cooperating with responsible local governmental and non-governmental agencies in their jurisdiction. Consortiums can develop the needed forum to organize and define mandates among involved stakeholders (local councils, Ag cooperatives, Ministry of Housing, NGOs, Governor, Donors, etc.…).

Activities To Manage Solid Waste Disposal

Municipal solid waste management is a major responsibility of local governments, typically consuming between 20% and 50% of municipal budgets in developing countries. It is a complex task that depends as much upon organization and cooperation between households, communities, private enterprises and municipal authorities as it does upon the selection and application of appropriate technical solutions for waste collection, transfer, recycling and disposal.

Figure 3. Canal Infestation with Solid Wastes

Furthermore, waste management is an essential task that has important consequences for public health and well-being, the quality and sustainability of the urban environment and the efficiency and productivity of the urban economy. In most villages of Egypt, waste management is inadequate: a significant portion of the population does not have access to a waste collection service and only a fraction of the generated waste is actually collected. Systems for transfer, recycling and/or disposal of solid waste are unsatisfactory from the environmental, economic and financial points of view.

To achieve sustainable and effective waste management, development strategies must go beyond purely technical considerations to formulate specific objectives and implement appropriate measures with regard to political, institutional, social, financial, economic and technical aspects.

Again, the main role of the MWRI IWMDs in this regard is to raise awareness and educate BCWUAs members about health and environmental implications of dumping solid wastes into irrigation systems. Respectively, the role of BCWUAs members is to first, extend dissemination of this awareness and education to all stakeholders and water users in their areas. Second, the BCWUAs should play a key role in adopting site-specific practical techniques for solid waste disposal and management through cooperating with responsible local governmental and non-governmental agencies in their jurisdiction.

BCWUA Awareness/Capacity Building Activities

Three levels of activities were structured to support and enhance awareness raising and capacity building at the local and IWMD level (Figure 2);

1. BCWUAs Chairpersons
Two main activities should be implemented to build the capacity of BCWUAs chairpersons:
a. Holding Seasonal meetings that gather all BCWUAs chairpersons at the IWMD level with IWMD managers and section heads.
b. BCWUAs chairpersons' orientation workshops to be conducted on annual basis with the objective of building the capacity of BCWUA chairpersons regarding the IWMD-BCWUA relationship, roles and responsibilities, and participatory management framework,

2. BCWUAs Board Members
Two main activities were implemented to build the capacity of BCWUAs board members:
a. Holding regular meetings that gather each BCWUA board members at the branch canal level with IWMD managers and section heads.
b. BCWUAs board members workshops, that is conducted in each district to cover all their BCWUAs. The target group of the workshops is all BCWUAs board members.

Prior to these workshops Each and every BCWUA had assigned their board members with specific roles and responsibilities according to the applied participatory water management framework. One of the main assignments that fall under the previously mentioned themes is targeting participatory water quality improvement activities.
The BCWUAs board members workshops are conducted with the objective of raising awareness and enable assigned BCWUAs board members to apply and activate participatory water management procedures at district and directorate levels, and achieve concrete outputs and benefits for each activity insuring gender equity.

3. BCWUAs Members and Water Users
Based on building the capacity of BCWUAs chairpersons and board members as mentioned above, they will in turn raise the awareness and build the capacity of the BCWUAs members and water users. Water users, through their BCWUA representatives, should be informed about water quality issues and involved in their resolution. Three levels of awareness activities should be considered:
Through the seasonal meetings, IWMD staff should sensitize chairpersons about water quality degradation sources and impacts and provide information regarding water quality in the canals, drains and groundwater;
Through individual meetings with Board members, IWMD staff should discuss local water quality and pollution issues and encourage water users' involvement and responsible behavior;
Within each BCWUA, Board members and WU representatives should convey to all water users information regarding pollution causes and consequences. This can be done through large gatherings, meetings, fact sheets, and media. The BCWUA will document these awareness events through minutes of meetings.

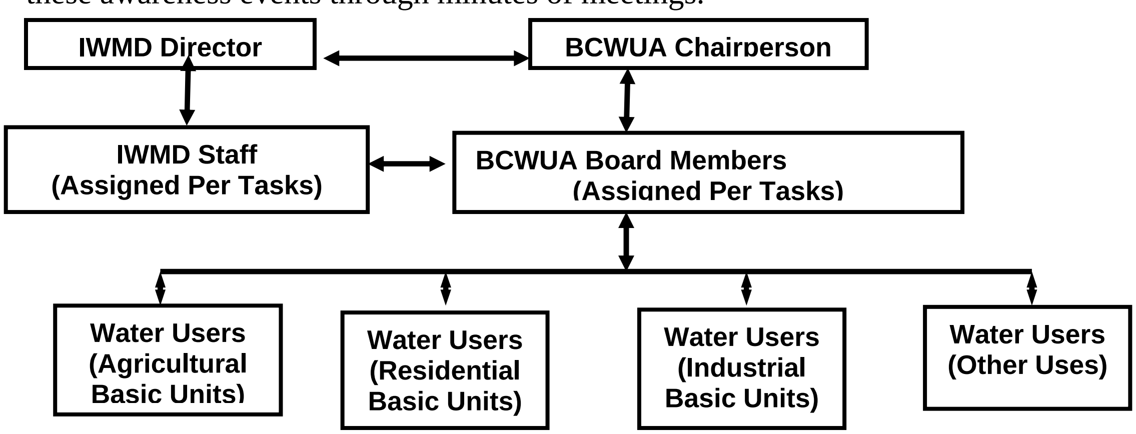

Figure 4. Proposed Structure for Participatory Awareness, and Capacity Building

Finally, the overall objective is not only to raise awareness of water users but also to involve them as responsible actors. While infrastructure constructions are sometimes needed, water quality can also be improved through changes in everyday practices, notably regarding the disposal of liquid and solid waste

RESULTS AND SUCCESS STORIES

Among the significant outputs from the involvement of BCWUAs, is a marked decrease of recorded complaints from water users, as well as an improved handling of violations (tampering with water structures or canal banks, illegal constructions, illegal releases or withdrawals, etc.). Violations used to be recorded by MWRI staff and after a couple of warnings, referred to the police for follow-up (follow-up being rare but potentially violent). Nowadays, violations are discussed with Board members, solutions facilitated to the satisfaction of all parties involved. Increased awareness also prevents the occurrence of such violations.

Among other successful outputs, dozens of BCWUA success stories have been collected by the MWRI IWMU. Some of these refer to the collection of money among water users to handle cleaning works to complement or supplement MWRI activities. Voluntary labor also occurred in some branch canals, mostly for de-weeding purposes. Sizeable lengths of branch canals were cleaned from garbage disposal or violations such as tree planting through collaboration between BCWUAs and IWMD staff. Conflicts and disputes among water users have been mediated and solved by BCWUA Boards with limited or no involvement from IWMD staff.

As mentioned earlier, gender equity is promoted through the selection of women as representing non-farming (resident) water users. There is growing awareness among farmer representatives of the need to involve women: as an example, garbage dumping in canals is a general concern. Awareness activities to prevent dumping have to proceed from household to household and target women. Only women WURs and Board members can carry out such activities and visit other women.

CONCLUSION

The IWMD establishment is an essential prerequisite to establish BCWUAs. The IWMD existence supports greatly the sustainability and the incremental promotion of participatory water management at local level. The expansion of the IWMD concept at national level then is the first step towards integrated water resources management and stakeholders effective involvement.

BCWUAs empower water users to better assess their needs and priorities, solve local water disputes and issues on their own, and partner with MWRI staff to solve larger-scale issues. BCWUAs contribute to better water management because of their ability to engage water users as active participants, not passive beneficiaries. They also provide an effective communication channel between water users and the MWRI. Finally they are able to resolve conflicts among water users and coordinate their individual needs, concerns, priorities and activities.

BCWUAs provide improvements in water quality because BCWUAs can raise awareness and contribute to activities to reduce the pollution caused by uncontrolled waste releases.

Increases in water use efficiency, water quality protection and improvement, and in agricultural productivity and incomes derive from these improvements while reductions in O&M costs result from better decision making, improved project designs, better identification of priorities and better allocation of funds.

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FLOW MEASUREMENT WITH LONG-THROATED FLUMES UNDER UNCERTAIN SUBMERGENCE

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ABSTRACT

The evolving circumstances under which irrigation districts operate include growing demands for more accurate knowledge and accountability of flow throughout the conveyance network, along with increased needs for timely awareness when unexpected flow conditions are present. For open channel conveyance systems, critical-flow structures (flumes or weirs) offer the simplicity of a direct correlation between upstream water level and a corresponding discharge. Unfortunately at many locations where flow measurement is desired there may be insufficient head available for operation of a critical-flow measurement structure under all flow conditions that may occur.

In recent years following development of computer-based design and calibration software, long-throated flumes have gained increasing popularity as the class of critical-flow structures which offer the greatest submergence tolerance. Numerous long-throated flumes have been installed at sites where head availability is marginal. In some cases after a flume has been installed it becomes apparent that the head is not sufficient under all operating conditions for critical-flow measurement. Reclamation's Hydraulic Investigations and Laboratory Services Group and Yuma Area Office Water Conservation Field Services Program are field testing a system for measuring flow with long-throated flumes under submerged or unsubmerged conditions.

The initial scope this field study targeted specifically selected for continuously submerged conditions. The project scope has been expanded to include occasionally submerged sites in recognition that numerous long throated flumes have been installed at sites where submergence conditions that exceed the flume's modular limit exist under some operating conditions.

INTRODUCTION AND BACKGROUND

Engineers at the US Bureau of Reclamation (Reclamation) Hydraulic Investigations and Laboratory Group have recently been expanding on the work of others (Replogle, 1994) in low-cost pipe venturi flow measurement by applying the venturi solution for measuring flow at submerged flumes. For the pipe venturi solution, the measured static head differential along with known cross sectional flow areas from two locations – the venturi approach section and the constricted throat section – are needed to determine

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discharge rate by simultaneously solving relationships for conservation of energy and conservation of mass.

$$Q = C_d * \frac{A_1 * A_T}{\left(A_1^2 - A_T^2\right)^{0.5}} * \left(\frac{2g}{\alpha} * \left(H_1 - H_T\right)\right)^{0.5} \qquad \text{Equation 1.}$$

Where:

Q = Discharge (ft^3/s)
C_d = Discharge coefficient – determined empirically
A_1 = Cross section flow in the meter approach section (ft^2)
A_T = Cross section flow area in the constricted throat section of meter (ft^2)
g =Gravitational Acceleration (= 32.2 ft/s^2)
α = Velocity distribution coefficient (a value of 1.02 is commonly used)
H_1 = Approach section static head (ft)
H_T = Throat section static head (ft)

Center line of meter must be horizontal
H_1 and H_T measured from a common datum

For application of this solution to an open channel structure, both the approach section and a constricted throat section must be prismatic in shape for a sufficient distance to ensure parallel flow lines past the static head measurement point of each section. This requirement is consistent with geometric requirements for a critical-flow long-throated flume. The critical flow long-throated flume calibration procedure also functions by simultaneous solution for conservation of energy and conservation of mass. Long-throated flume calibration utilizes an iterative process, whereby an appropriate approach section level is converged upon that corresponds with the unique critical depth at the throat for a given discharge.
Notable factors in comparing application of the venturi solution to a pipe meter with using the venturi solution on a long-throated flume are the magnitude of head differential observed as flow moves from the approach section, then is accelerated through the constricted throat sections. Pipe meters may be designed to provide a significant head differential (ranging from a few tenths of a foot to multiple feet) over the desired measurement range that enables a comparatively high degree of resolution in determining flow rates, yet impose comparatively small head loss on the system

In contrast, the magnitude of head differential seen for long throated flumes would typically be considerably smaller than the head differential seen using a pipe meter. For example, in a field data set discussed below measured differential at a submerged flume over a 6 hour period ranged from 0.021 ft. to 0.11 ft while corresponding submergence rates varied from 98.8% to 93.0% respectively. With the smaller ranges of head differential available, precision in measuring water levels is an important factor in obtaining flow measurements of desired accuracy with a flume using the venturi solution.

LABORATORY TESTS

Limited-scope laboratory tests were performed at Reclamation's hydraulics laboratory in 2003 and 2004. Both test series utilized a laboratory model in which a laterally contracted flume was installed at mid reach of a trapezoidal channel. A ramp-type long-throated flume was installed at the downstream end of the channel. The ramp flume served both to force submergence on the laterally-contracted flume and also functioned for obtaining control flow measurements against which to compare flow calculations from the submerged flume. Figure 1 is a photo of the laboratory test channel looking downstream.

Figure 1. Laboratory Test Facility

During the 2003 testing, all water level measurements were made using a single stilling well equipped with a hook-type point gage capable of least readings of 0.001 ft. This well was connected by a valved manifold to each tap location on the test channel where water level measurements were needed. In the testing procedure, each time the stilling well was connected to a different tap, level readings were repeated at 5 minute intervals until consecutive readings were unchanged, indicating the stilling well had reached equilibrium level with static pressure at the tap.

Results from the 2003 tests showed a promising level of agreement between flow rates determined by the ramp flume and the submerged flume. The single stilling well water level measuring system that had been employed did not appear to be practical for field applications. During the laboratory tests, it had required as long as 30 minutes to confirm the stilling well was in equilibrium with static pressure at a tap. Given that water levels representing static head at two taps must be determined to apply the venturi discharge equation, a means of more rapidly determining water levels with a suitable degree of accuracy would be imperative in moving this measurement technology into field tests.

Laboratory testing in 2004 focused on identifying a means of obtaining water level measurements in a timely manner that could translate into practical field application of the technology. For the 2004 tests, stilling wells were installed at each channel tap. A bubbler sensor was utilized to electronically sense water levels. In order to minimize variability that use of multiple sensors would introduce, a single bubbler unit was used to read all taps by physically connecting and disconnecting an air line from the bubbler apparatus to taps in the various stilling wells. Using a bubbler sensor in this manner, the time required to obtain water level measurements needed for application of the venturi discharge equation was reduced to no more than a couple of minutes. The potential for further simplifying reading multiple water levels with a bubbler sensor by adding a solenoid valve controlled manifold to the bubbler output line was readily evident.

An additional feature of the 2004 test set up was the piping configuration of the stilling wells. Valves were installed in the line between each stilling well and channel tap. A line with a valve was also installed between each stilling well. This plumbing arrangement enabled all stilling wells to be isolated from the laboratory channel and to be observed with a common level at all wells. This configuration greatly simplified initial calibrations and subsequent calibration checks in assuring that sensor offset values for the respective taps reflect a common datum to the accuracy limits of the bubbler sensor. Results from the 2004 testing again showed a promising level of agreement between discharge computed for the submerged flume and discharge determined at the ramp-type long-throated flume. Figure 2 is a plot of the 2004 tests.

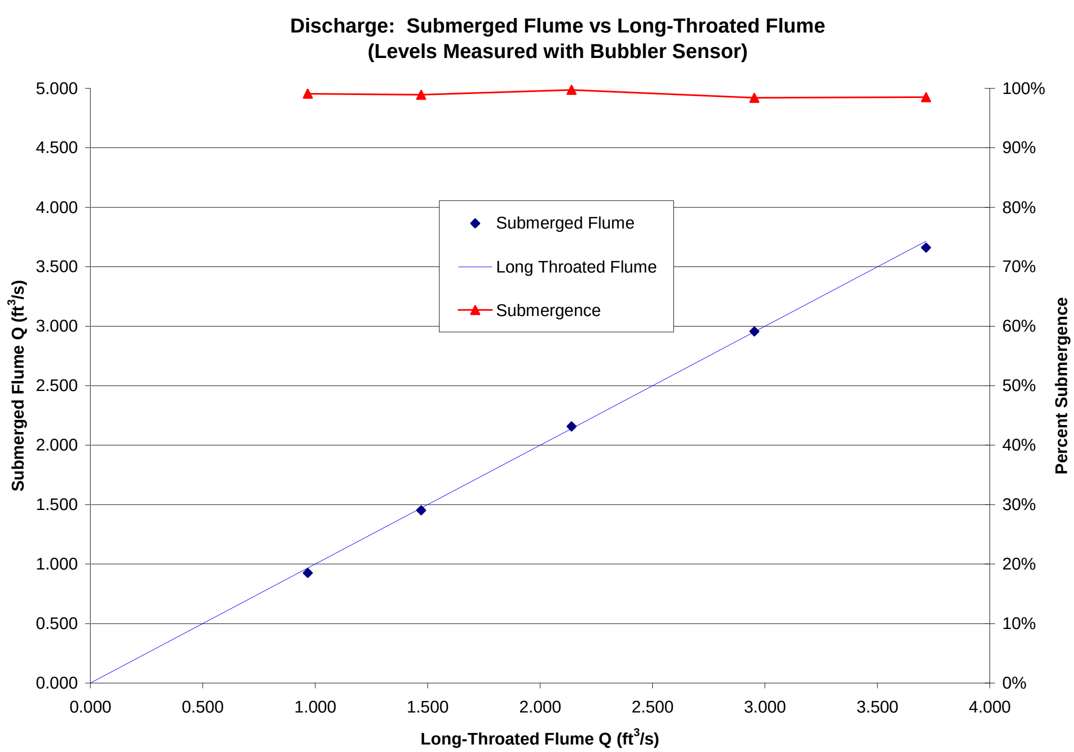

Figure 2. Comparative discharge calculations from 2004 laboratory tests

FIELD TESTS

University of Arizona Valley Farm Site An initial submerged flume field site was installed in early 2007 at the University of Arizona Valley Farm in cooperative effort including the University of Arizona Extension Service, Reclamation's Yuma Area Office

Water Conservation and Field Services Program, and Reclamation's Hydraulic Investigations and Laboratory services group. This site is located approximately 30 feet downstream from a location where flow exits a pipeline into a concrete lined channel. No measurement structure was previously in place at this site. Figure 3 shows freshly placed concrete that forms a laterally contracted flume at the University of Arizona Valley Farm site.

As a result of a leaking valve at the head of the upstream pipe section, this site is constantly subjected to standing water at times of no discharge. Earthen berms shown in Figure 3 were necessary to isolate the flume during construction from this standing water. The standing water coupled with nearly flat canal slope create excessive submergence conditions for operation of a critical-flow flume at this location.

Figure 3. University of Arizona Valley Farm submerged flume site

Two large vertical pipes seen at the right of the freshly placed concrete flume are stilling wells. Three smaller vertical pipes are access-ways to valves in each line between the canal and respective stilling well and a line between the two stilling wells. Two float & pulley level sensors were installed for water level measurement at this site. At the time of installation, a bubbler sensor configuration capable of automatically reading multiple taps was under development at Reclamation's hydraulics laboratory but was not yet available for use at this site.. A programmable logic controller (PLC) calculates water levels from sensor inputs and calculates discharge rate on three-minute cycles. Calculated values are shown on an LED Display.

Discharges of approximately 5 ft^3/s and 10 ft^3/s as measured using the venturi solution at this site were compared with stream gated values using a Price AA meter and found to be within 10% agreement. Based on initial observations at the University of Arizona Valley Farm site, YAO inquired about application of the venturi discharge solution at existing long-throated flumes that had been designed assuming critical-flow operation, but which at times are subjected to submergence that exceeds modular limits. Following these conversations, contacts were made with both the Unit B Irrigation District and the Yuma County Water Users Association (YCWUA). Plans for three additional field sites, one at Unit B, and two at YCWUA emerged from these contacts.

Unit B Irrigation District Site: At the Unit B district a site was selected where no measurement structure had previously existed. The site is the head of a concrete-lined lateral with limited head availability. When water is conveyed in the lateral, a discharge rate of 10 ft^3/s is the consistently targeted delivery rate. Submergence conditions at this flume, seen in Figure 4, are expected to exceed modular limits during water deliveries.

Figure 4. Unit B District Flume

A laterally-contracted “insert” flume pre-constructed of plastic lumber by Reclamation’s YAO shops was installed at the Unit B site in November of 2007. A PLC with integral data communications radio was installed along with a bubbler sensor. At the time of this installation, a prototype bubbler sensor with a solenoid valve bank capable of reading multiple water levels had been configured and tested at Reclamation’s laboratory. Ae bubbler sensor unit with solenoid valve bank are seen in Figure 5 linked to a radio/control unit.

A concept employed for the Unit B and YCWUA field sites was to include measurement of actual submergence rate. To measure submergence the bubbler sensor was equipped with three solenoid valves to measure water levels in the upstream, throat and downstream sections of each flume. Upstream and downstream levels are needed to determine submergence, while upstream and throat levels are needed for the venturi solution.

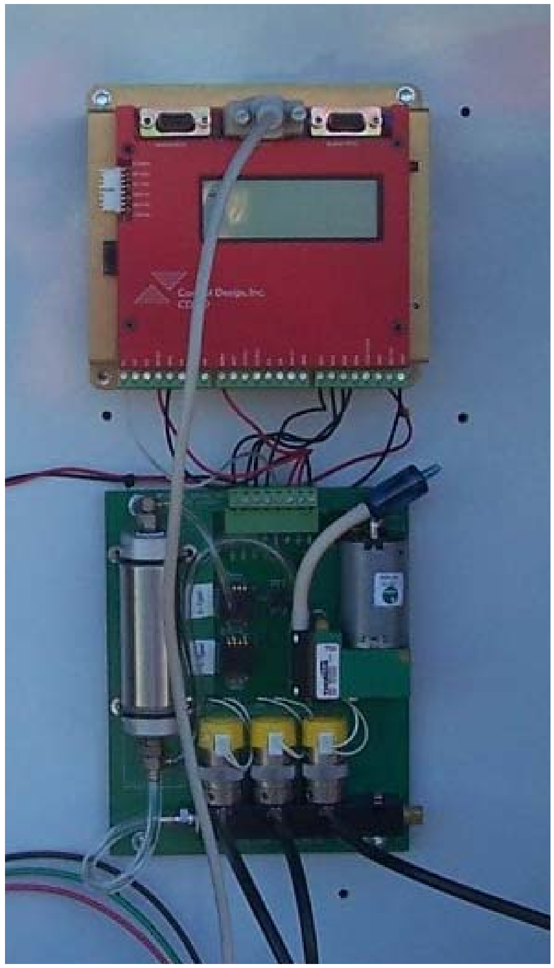

Figure 5. Radio/Control unit &
Bubbler w/ Solenoid Valve Bank

Figure 6. YCWUA Potter Flume

Figure 7. YCWUA Cumming Flume

<u>YCWUA Sites:</u> Two YCWUA sites were selected where existing long-throated flumes operate at times at submergence rates that exceed modular limits for critical-flow

operation. At the head of YCWUA's Potter lateral, the district has recently installed a ramp-type long-throated flume. At the head of YCWUA's Cumming lateral, the district had recently installed a long-troated flume featuring both lateral contraction and a ramp in the flume invert. Submerged flow instrumentation was installed at the flumes on each of these laterals in November of 2007. Figure 6 and Figure 7 are photos of the Potter and Cumming sites respectively (both views looking downstream).

In an effort geared examining a reduced cost installation alternative, the Unit B site and both YCWUA sites were initially set up without stilling wells. Bubbler lines were attached to the flume walls underneath PVC arc sections made by splitting a six-inch PVC pipe longitudinally into approximately four-inch wide strips. The bubbler tap itself was created by gluing a 90 degree, 1/8" tubing hose barb fitting into a hold in the PVC arc shield, then cutting the fitting flush with the outer surface of the shield. The green PVC arc shields may be seen installed on the leftt side of the channel at the Potter Flume in Figure 6 and the right side of the Potter lateral in Figure 7.

While installing bubbler lines on the flume walls made for a simple installation, establishing a common datum among bubbler taps with any degree of precision was a considerably greater challenge than was the case for the University of Arizona Valley Farm site with stilling wells linked by valved lines. Four months after the installations at the Unit B flume and the YCWUA Cumming and Potter sites, linked stilling wells were installed at each of the three flumes with upstream, throat and downstream taps, and the surface mounted bubbler lines were abandoned

With the linked stilling wells installed, sensor calibrations were performed at the Unit B and both YCWUA sites with accurate identification of a common datum. YAO staff suggested an effective means of creating a comprehensive data record for verifying performance of the venturi solution would be to install an acoustic-doppler flow meter adjacent to the field test flumes to enable time series logging of flow measurements. YAO had two MGD Technologies Acoustic Doppler Flow Meter (ADFM) units available for installation. In an evaluation of the MGD ADMF technology that had been previously conducted at the Reclamation Laboratory, (Vermeyen, 2000), a similar unit was tested with discharge varying from approximately 12 ft^3/s to 30 ft^3/s. In these tests, the ADFM produced discharge measurements that showed a maximum variance of 11.8% compared with the laboratory control measurements.

The two YCWUA sites were determined to be the preferred locations for installing the available ADFM units given the varied range of submergence that is experienced at each of these sites, and in consideration of the fact that flow is rarely shut off in the Cumming and Potter laterals. In contrast, flow is present only occasionally at the Unit B and University of Arizona Valley Farm sites. An output signal from the ADFM unit output would be fed into the on-site PLC unit. Information logged on the PLC included measured submergence rate, discharge measured using the venturi solution, discharge measured using the flume rating and upstream level, discharge calculated by the ADFM, and a time stamp.

For the ADFM installation at the YCWUA Potter site, a wide flange steel beam was placed approximately 30 feet upstream from the flume. An electrical enclosure with a solar panel attached to the enclosure lid was installed on the beam to house the ADFM control unit and batteries. The ADFM transducer was mounted on a steel plate to which a steel tube was welded such that the tube could be clamped to the wide flange beam to anchor the ADFM transducer to the canal invert. Figure 8 is a photo of the ADFM placement at the YCWUA Potter site.

Figure 8. ADFM unit at Potter Flume

Figure 9 ADFM unit at Cumming Flume

For the Cumming site, a bridge of plastic lumber was constructed over the flume approach section. Similar to the Potter installation, the ADFM transducer is attached to a steel plate attached at an orientation normal to a pipe. The pipe is clamped to the bridge to secure the ADFM transducer to the structure invert. The instrument enclosure and solar panel are positioned along side the flume as may be seen in Figure 9.

FIELD RESULTS

Effectiveness of using the venturi flow calculation method with long-throated flumes under submerged or unsubmerged conditions is shown in the following 24 hour time series plots including periods of differing submergence conditions. Figure 10 is a plot of flow at the YCWUA Cumming flume for the 24 hour period of February 15, 2009. Data collected included flume submergence and flow as calculated by 1) critical flow flume rating based on upstream level, 2) venturi flow calculated using upstream and throat levels, and 3) flow calculated by the upstream acoustic doppler ADFM device.

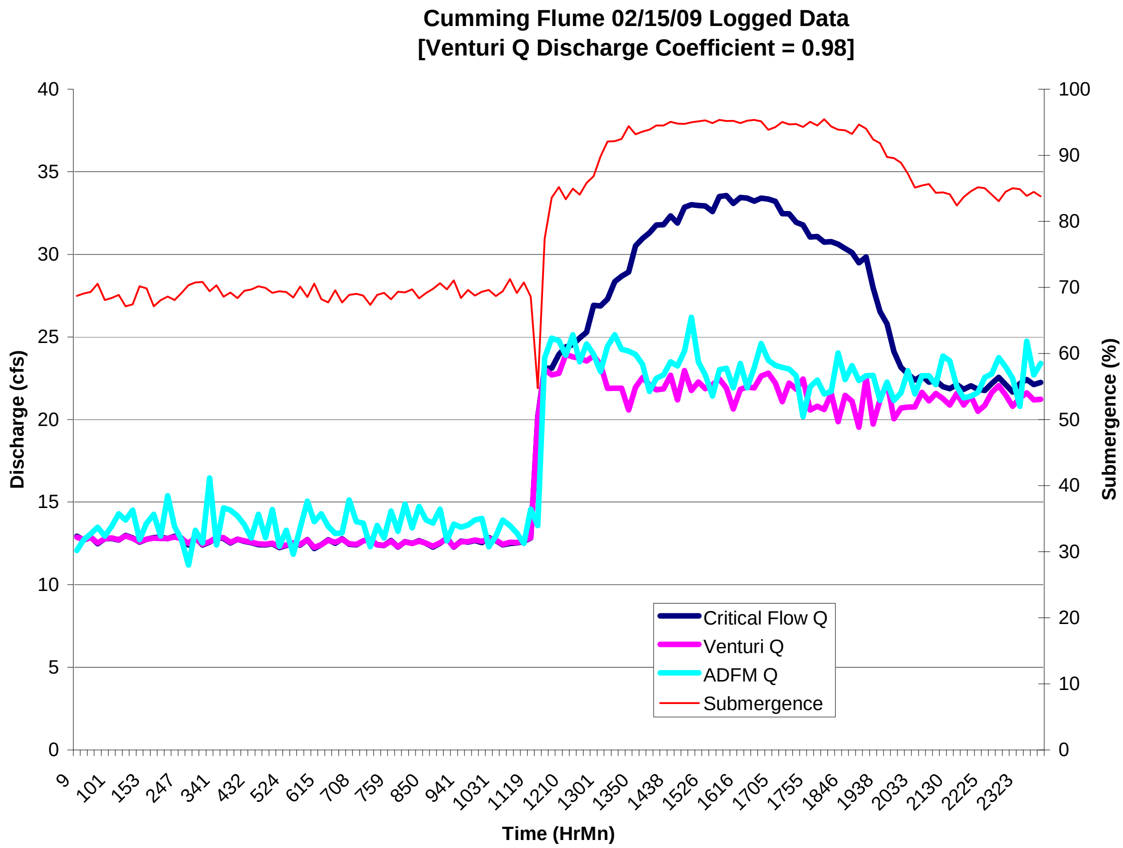

Figure 10. Plot of Discharge Under Varied Submergence at Cumming Flume

Figure 10 represents operation on a day where discharge was adjusted at mid day from about 13 ft^3/s to around 55 ft^3/s. At the lower flow, measured submergence was in the range of 70%, well below the modular limit for the flume. Hence flow calculated using the flume rating and upstream level would be valid. The plot suggests that at a submergence rate between 80% and 85%, modular limit for the flume was exceeded, and flow calculated using upstream level and the flume rating began to yield excessively high values.

Interestingly, at submergence rates below the modular limit, flows calculated using the upstream level and the flume rating are virtually identical to flow calculated using the venturi solution based on both upstream and throat levels. At submergence rates in excess of the modular limit, the relation between discharge measured using the venturi solution maintains a similar relationship to the ADFM calculated discharge that is seen at lower submergence.

Figure 11 is a plot of data from the YCWUA Potter flume for the 24 hour period of April 4, 2009. During the field testing, the Potter was observed to rarely operate under excessive submergence. For the data plotted below, the nearest downstream check was operated to deliberately create a high submergence rate which was incrementally reduced in approximately 30 minute time steps over approximately a 6 hour period.

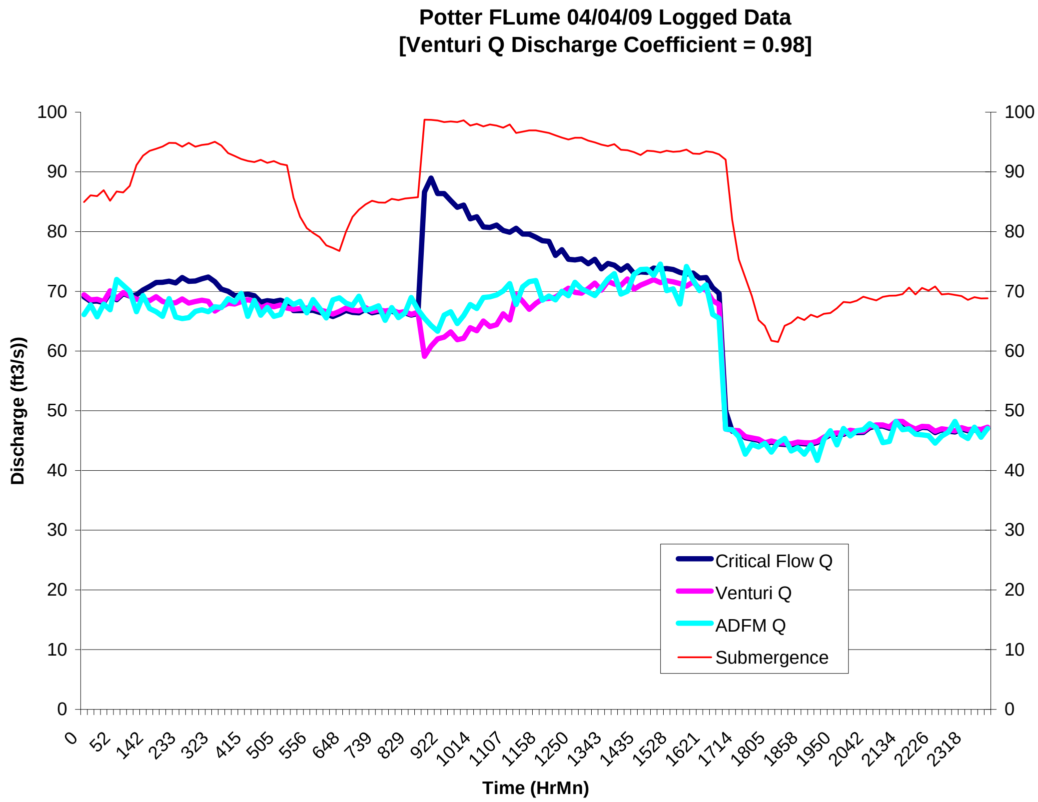

Figure 11. Plot of Discharge Under Varied Submergence at Potter Flume

The plot of data from 04/04/09 at the Potter flume suggests that the modular limit of the ramp-type flume at Potter is around 90% submergence compared with the 80% to 85% submergence modular limit suggested by data from the Cumming flume which is laterally contracted along with having a modest height raised crest. Much like the Cumming flume data of Figure 10, at submergence levels below the modular limit, flow calculated using upstream level with the flume rating and flow calculated using the venturi solution are virtually identical. At submergence rates in excess of the modular limit, discharge measured using upstream level with the flume ration is excessively high while the venturi solution discharge tracks much closer to the upstream ADFM unit.

SUMMARY

What was initiated in laboratory studies as a means of measuring flow under submergence rates that constantly exceed modular limits of a long-throated flume has been adapted in field trials to examine viability of using the venturi flow measurement solution under either submerged or unsubmerged conditions. In laboratory tests the venturi measurement system has been shown to be a viable means of obtaining measurements of reliable accuracy under submergence rates in excess of flume modular limit, given a means of accurately measuring water levels in the approach and throat sections of a long-throated flume.

In the field testing, the concept was expanded to look at developing a system for measuring flow at long-throated flumes that may or may not be submerged. The initial concept applied in the field tests was to first measure submergence, then utilize the flume rating and approach section water level for submergence conditions less than the modular limit, or for submergence rates that exceed the modular limit, use the venturi solution with approach section and throat section water levels to determine discharge.

From the field test data presented, it is apparent that the venturi solution may be used with long-throated flumes for submergence rates less than the modular as well as for submergence rates in excess of the modular limit. Thus it is not necessary to determine the degree of submergence. The practical impact is that only two water levels – the approach level and the throat level – are needed to measure flow at a long-throated flume under any submergence condition.

Efforts associated with the field testing have been unsuccessful in identifying an alternative to construction of stilling wells that can be isolated from the canal and linked together to simplify accurate level sensor set-up calibration and calibration checks. At present the linked, multiple stilling well configuration appears to be a key feature for practical use of the venturi solution with a long throated flume. Accurate determination of a common datum for multiple stilling wells is essential for obtaining differential head measurements with the resolution needed for discharge measurement precision using the venturi solution.

Use of long-throated flumes equipped to accurately measure both approach and throat water levels to enable use of the venturi solution may represent a discharge measurement alternative to emerging technologies including acoustic doppler, radar, and others for conditions of excessive or of uncertain submergence. Long-throated flumes equipped for venturi solution measurements may in many cases represent enhanced cost effectiveness, enhanced accuracy, and enhanced reliability for measuring discharge under limited head availability conditions compared with these alternatives.

DISCLAIMER

No warranty is expressed or implied regarding the usefulness or completeness of the information contained in this paper. References to commercial products do not imply endorsement by the Bureau of Reclamation and may not be used for advertising or promotional purposes.

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DEVELOPING NEW WATER SUPPLIES IN FRESNO IRRIGATION DISTRICT THE WALDRON BANKING FACILITIES

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ABSTRACT

Fresno Irrigation District (FID) serves irrigation water to approximately 245,000 acres including the Cities of Fresno and Clovis, in California's Central San Joaquin Valley. As Clovis has developed they have looked for ways to diversify their water supply portfolio. Until recently, this mainly consisted of groundwater wells with some surface water supplies coming from FID. Clovis, in an effort to increase their dry year supplies, partnered with FID to develop the Waldron Banking Facilities.

Through the agreement developed between Clovis and FID, Clovis provided half of the capital to develop the project in return for half of the project yield. Clovis also has the first right of refusal, on an annual basis, for any yield developed from the project. The Waldron Banking Facilities are comprised of three groundwater banking facilities located in the western portion of the District. In exchange for the banked supplies, FID then provides an equivalent amount of surface water to Clovis (in the eastern portion of FID). To develop a new water supply for the City and FID, during wet years and other times when surplus surface water supplies are available these supplies are routed to the groundwater recharge basins. In dry years, these banked supplies are then recovered from the aquifer, and delivered to FID growers.

Two of the recharge basin sites were existing regulation basins, which were significantly expanded to add recharge capabilities. One of the sites is new, and placed at the bifurcation of one of FID's laterals. The recharge basin sites were strategically selected in order to provide an added benefit as regulation and storage basins that could be utilized during the irrigation season.

The project was built over the course of three years, in phases. Now complete, the project includes approximately 250 acres of recharge basins, new measurement and control sites, seven recovery wells, and a network of monitoring wells. This paper will discuss the financial aspects of the project, project planning issues, design considerations, and how the twelve construction contracts were developed, managed and executed.

NEW SUPPLIES

The Waldron Banking Facilities Project (Project) is an agricultural and urban project that provides water to urban suppliers, agricultural suppliers, and facilitates the environmental benefits of improving a river fishery. The Project is divided into three separate facilities

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totaling 250 acres (Waldron – 160 ac., Empire – 32 ac., Lambrecht – 58 ac.). Figure 1 is a map of the District showing the locations of the three sites, and the channels used to convey surface water to them.

The new supplies are developed by capturing flood waters and surplus supplies in above normal years and recovering them during below normal years, rather than letting those supplies go unused during the above normal years. The Project utilizes a combination of flood water, fisheries management water, allocations from the San Joaquin River during above normal years, and flood water from the San Joaquin River. A brief description of each source is described below.

> Local Stream Flood Water. This includes water from Big Dry Creek, Mud Creek, Fancher Creek, Redbank Creek and Dog Creek.
>
> Local Storm Water. Some of the storm water that falls within the Fresno-Clovis area is diverted into FID facilities as part of an agreement between Fresno Metropolitan Flood Control District (FMFCD), Clovis, Fresno, the County of Fresno and FID to route storm waters through the urban area. Stormwater is either diverted directly into FID's facilities, or collected into FMFCD storm basins and later pumped into FID's facilities.
>
> Kings River Flood Water. Kings River flood water was estimated based on flow records kept by the Kings River Water Association for the James Bypass. These flows represent only the significant Army Corps of Engineers directed flood release from Pine Flat Dam, and do not account for minor flood releases of downstream intermittent stream flows.
>
> San Joaquin River Section 215 Water. Flood water, called Section 215 water, from the San Joaquin River has also historically been made available to agencies that have the ability deliver it. FID diverts San Joaquin River water into its facilities from the Friant-Kern Canal.
>
> Kings River Fisheries Management Program Framework Agreement Water. Under an agreement entitled, the *Kings River Fisheries Management Program Framework Agreement*, the District is required to maintain a minimum flowrate in certain sections of the Kings River to help establish a fishery along the river. FID is currently obligated to route a minimum of 45cfs daily during months when flows are below 90cfs to the headgates of FID's Fresno Canal.
>
> San Joaquin River Class II Water. FID currently holds a contract for 75,000 AF of Class II San Joaquin River water that it receives from the Friant-Kern Canal. Class II water is not made available in below-normal years.

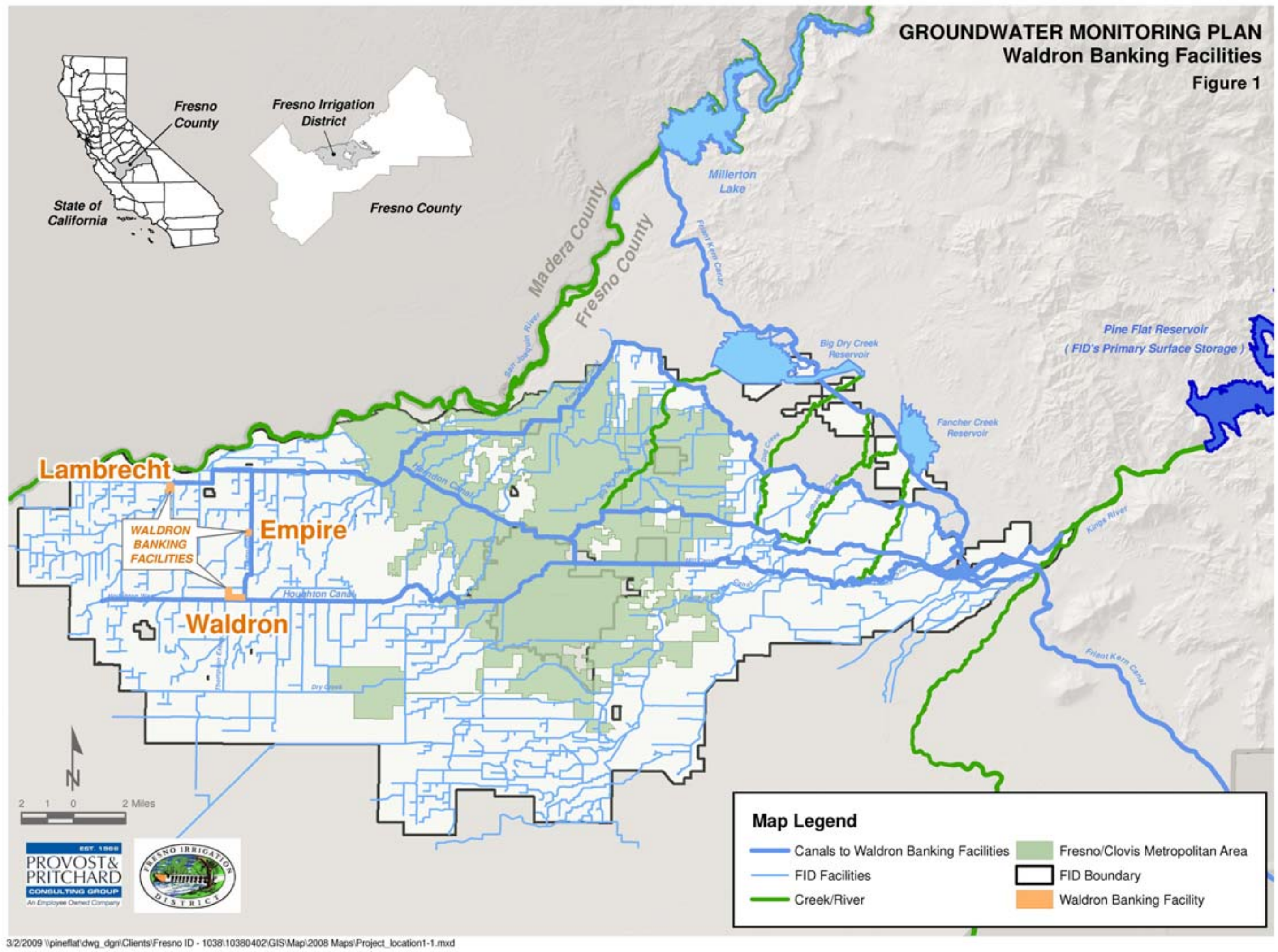

Figure 1. Map of the Waldron Banking Facilities

A review of the records from the 50 years prior to the study showed that on average approximately 11,500 AF could be routed to the Project for recharge. Leaving 10% of the recharged water behind to account for losses and mitigate potential impacts to adjacent landowners, the Project would net approximately 10, 350 AF on an average annual basis.

PROJECT FUNDING

While 10,350 AF of supply represents about 2 to 3% of FID's dry year supply from the Kings River, it represents a significant dry year supply to the City of Clovis (Clovis). Clovis typically uses 25 TAF in a normal year, 70% is derived from surface water and 30% from groundwater wells.

In planning for new growth, Clovis recognized the need to develop a new water supply and further increase their dry year supply. This need for new water supplies led Clovis to partner with FID to develop the Project. As partners in the Project, Clovis agreed to fund half of the capital cost of the Project in exchange for half of the Project's yield. Clovis is given first right of refusal for water each year. Clovis is guaranteed 90% of the available banked water in any given year, up to 9,000 AF. If Clovis does not take water in a year, FID has the ability to use the water to serve their growers.

In 2000, California voters approved Proposition 13, the *Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection Act* (Prop 13). FID submitted a grant application under Prop. 13's Groundwater Storage Program to fund their half of the Project's costs. FID was awarded the grant and signed the contract to commence with the Project in 2004. The contract required that the Project be finished by the end of 2008.

DESIGN AND CONSTRUCTION

Design

The Project's design took into account a number of factors such as how quickly to get water into the basins, and recovered from the aquifer. In addition, the District wanted to make the best use of its capital investment, so each of the sites were designed to include flow regulation capabilities. Upgrades to the control gates and SCADA improvements were included.

Location. The Projects were sited such that they would:

1. Have geology favorable to groundwater banking.
2. Be far enough upstream in the District's distribution system that all of the recovered water could be used to satisfy downstream irrigation demands.
3. Be strategically located to regulate flows on main canals.

Recharge. The sites' primary purpose is water banking with flow regulation and operational storage a secondary benefit. Geologic explorations of each site were conducted to verify the shallow soil profiles would be conducive to recharge. Explorations of the deeper aquifer were also performed to determine the zones in which to draw the stored water. The geologic investigations and infiltration tests showed the sites' could sustain recharge rates between 0.35 and 0.5 ft per day. The recharge goal between the three sites was to place up to 13,000 AF (in anticipation of above average conditions) in the ground in approximately 8 months, or an average of 1,600 AF per month (0.21 feet per day). All of the sites had estimated sustainable recharge rates which were higher than the 0.21 feet per day needed which gave the District the ability to shorten the recharge season when needed.

Recharge could come in highly irregular flows and short bursts. Also when recharge basins when being filled for the first time will percolate at much higher rates. Recognizing the potential for the need to take high flows in short bursts, many design features were incorporated. The turnouts to each site were designed for relatively high flows, the sites divided into smaller cells, and sediment handling.

Table 1 below lists the sustainable recharge rate, acreage, and delivery inflow for each site. As the table shows, the design inflows are a minimum of about four times higher than the sustainable recharge flow. At the Empire and Lambrecht sites, the design inflows were based on the maximum flow that could be routed to the sites.

Table 1. Summary of Recharge and Inflow Rates.

Site	Sustainable Recharge Rate (ft/day)	Acreage	Sustainable Recharge Inflow (cfs)	Design Inflow (cfs)
Waldron	0.35	160	32	130
Empire	0.35	32	6	60
Lambrecht	0.50	58	15	90

Each site was divided into a number of cells. This gives the District the operational flexibility to fill basins in a sequence which would maximize surface storage using the least amount of acreage. This reduces evaporation losses and helps to minimize maintenance activities such as discing and spraying to control weeds, in years when large volumes of recharge water is not available. Without dividing the sites into smaller cells, water would be spread over much larger areas.

Also, given the source of the recharge water (floodwater, urban stormwater) it was anticipated that high sediment loads and trash would be delivered with the water. To mitigate the sediment one cell at each site was dedicated as a sediment cell. Dedication of the sedimentation cell also keeps sediment in one portion of the facility reducing maintenance, and reducing the potential for fine sediment sealing off the recharge cells. The sediment cell was designed with partial levees to create a labyrinth in which to slow water flow through the basin. The discharge out of the sedimentation cell to the other cells utilized a weir. This was done so that water from the top one foot of the sediment cell (the clearest water) would be delivered to the other recharge cells. Figure 2 is an example of the sedimentation cell configuration.

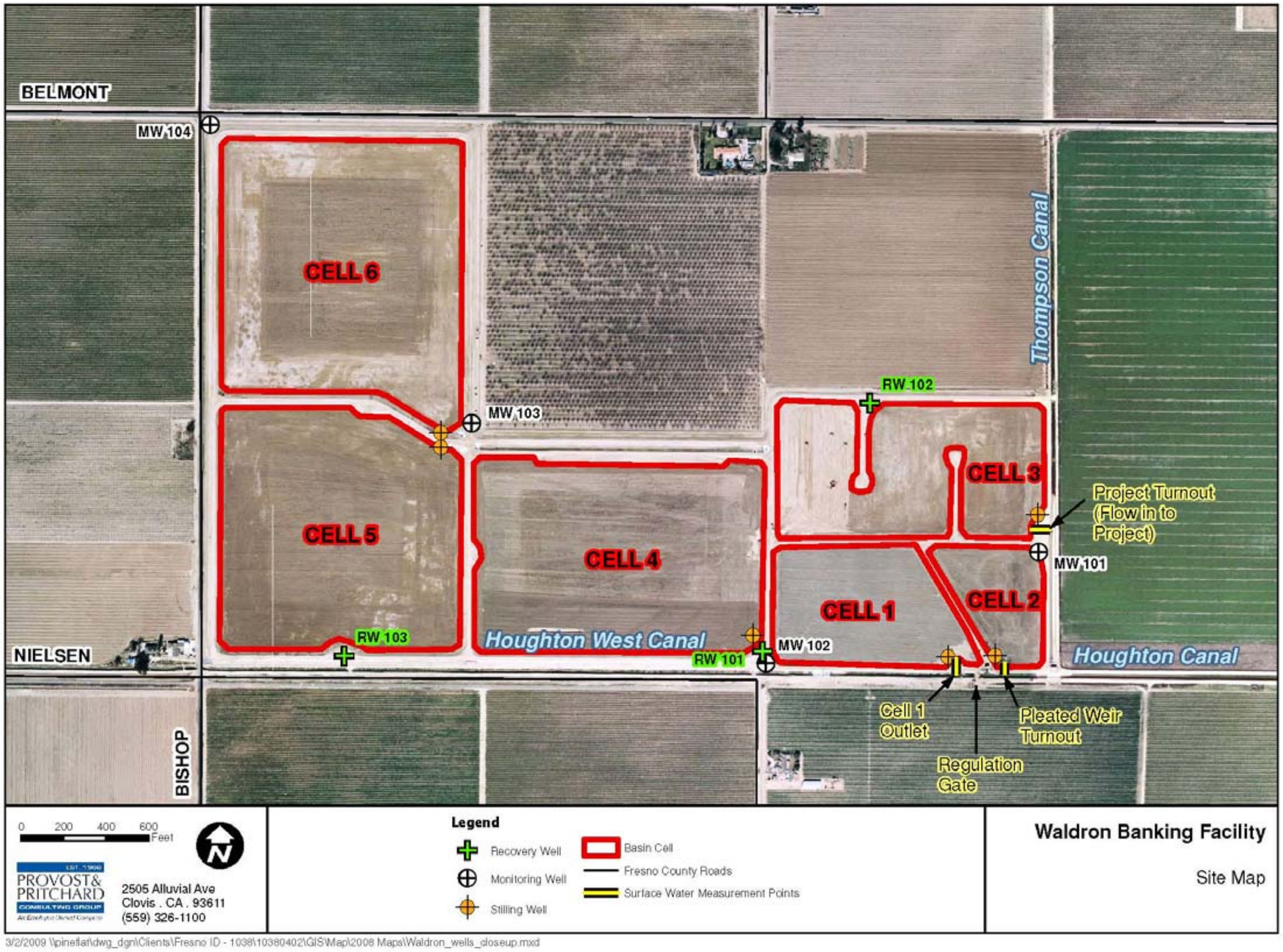

Figure 2. Site Layout

<u>SCADA and Controls.</u> Each site was located at a bifurcation in a canal system. The Waldron and Lambrecht sites had regulation capabilities. The Empire site added the benefit of a third regulation site. At each location, flows were able to be "reset" at each canal's headgate. Excess flows are directed into the basin through the use of a long-crested weir upstream of the canal headgates. Deficits in flows are made up through discharges from the basins to one of the canals at the bifurcation. Flow measurements are taken to control the gates and provide operational information. The flows are also totalized so that the net deliveries to the basins can be recorded and properly credited towards recharge.

The SCADA system not only controls the gates, but monitors and reports much of the data about the site to the District Office. Information related to the canal water levels, canal flows, deliveries into and out of the sites, water levels in each recharge cell, recovery well pumping flows, and power consumption. In the future, the District plans to put data loggers in each of the on-site wells to collect daily groundwater level information, and potentially add remote starting capabilities to the wells.

<u>Recovery.</u> Seven wells were built for the Project. They can recover up to 12,000 AF of stored water in four months. All three sites are in cropped areas and many of the growers have their own wells. The wells can pump between 2,000 and 4,000 gpm with average pumping depths of about 180 feet. All of the wells are equipped with flowmeters that totalize the amount pumped. The recovery wells were drilled at lower depths than the surrounding wells in an effort to minimize interference. Typically, the nearby irrigation wells are completed to a depth around 300 to 400 feet. The recovery wells were completed to a minimum depth of 500 feet. Table 2 below lists the recovery capability for each site.

Table 2. Recovery Ability Summarized by Site

Site	Recovery Flow (cfs)	Number of Wells
Waldron	22	3
Empire	6	1
Lambrecht	22	3

A monitoring network was also developed around the sites. The network involves on-site and off-site wells. A total of 10 monitoring wells were built at the sites to collect more detailed information about how the Project is affecting local groundwater conditions. The District collects water levels at least monthly in the monitoring network. The data is used to determine groundwater elevations, and determine groundwater flow direction. This includes determining the extents of pumping depression or recharge mounds, if any, which could result from the Project operations. Figure 3 shows both the recovery wells and monitoring wells at the Waldron Site. Groundwater flow in this area is typically in the southwestern direction.

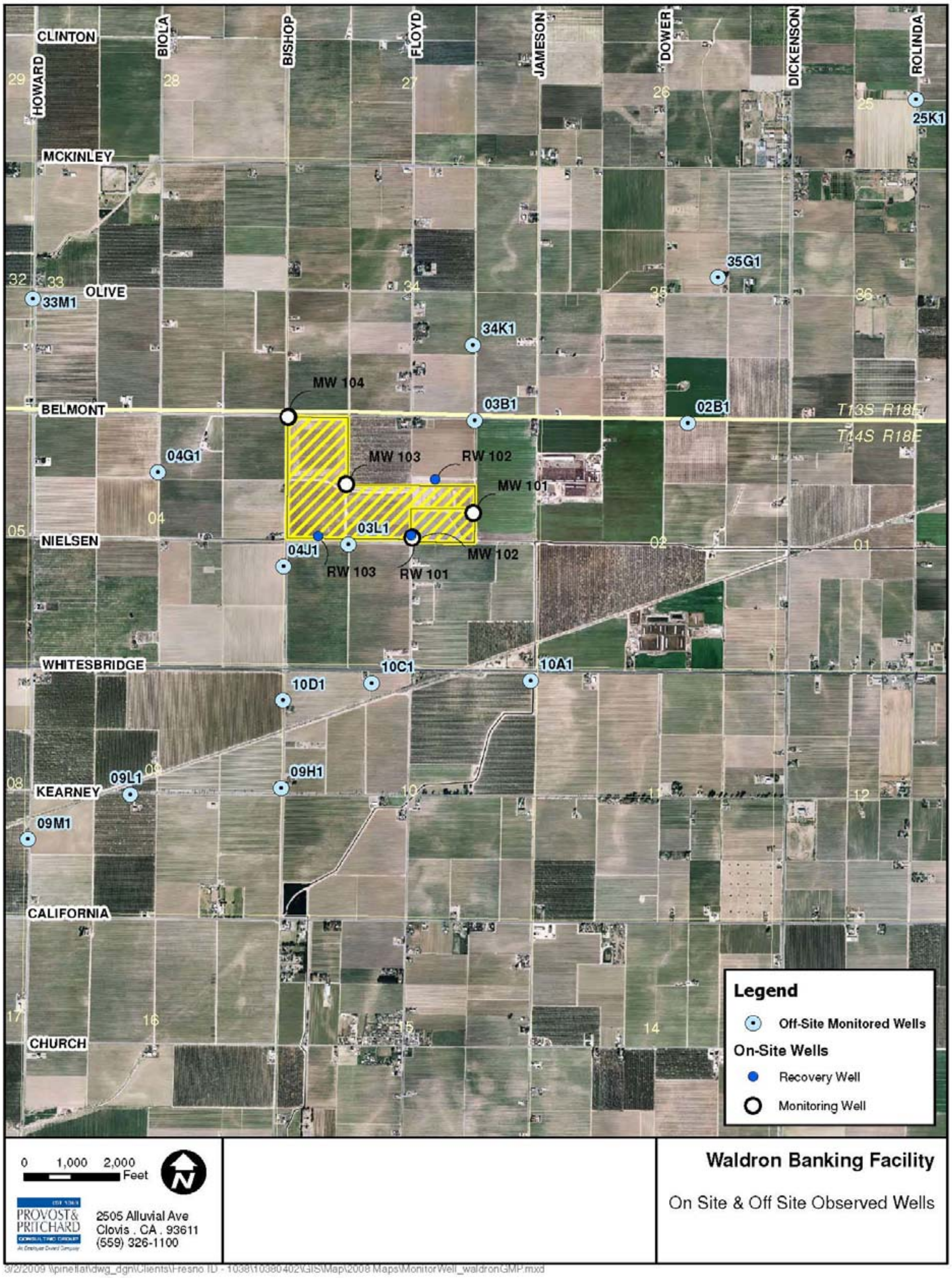

Figure 3. On Site and Off Site Observed Wells

Monitoring Committee. Given the fact that groundwater banking was new to FID, they wanted to involve adjacent landowners in the operations. A monitoring committee was established for the entire Project which included four representatives from the areas around each groundwater banking sites, and representatives from FID and Clovis. The monitoring committee meets at least annually to review the operational data, including recharged volumes, recovered volumes, groundwater levels, and groundwater quality. The main goal of the monitoring committee is to review the data and provide input related to the operations of the Project.

Construction

At the time the Project was ready for public bidding, housing developments were in their prime. This pushed labor and materials costs higher than they had been when the Project was first contemplated. This led the District to break the Project into multiple contracts, based on type of work. This was an attempt to secure lower prices by contracting directly with the companies doing the work, instead hiring a general contractor who would then subcontract the work. In total twelve contracts were bid, awarded, and completed. In general the contracts were broken up into the following categories:

- Demolition and Site Preparation
- Earthwork
- Structures
- Well Drilling
- Well Equipping

Because the work was split into multiple contracts, planning the sequence of which contracts would be underway at any time was critical. Construction began in January 2006 and was recently completed in October 2008. The construction for the Project followed typical construction procedures and methodologies. Typically no more than two contractors were working on-site at any time.

Demolition and Site Preparation work started the construction phase of the Project. At each of the sites, vineyards had to be cleared and irrigation systems abandoned. It was critical that the large root from the vines and all of the irrigation lines be removed so as not to compromise the integrity of the levees. Earthwork commenced shortly thereafter. The earthwork contractor moved approximately 150,000 cubic yards of material to build the Project levees. To make this work more cost-effective, the contractors were allowed to make deeper cuts close to the levees rather than skimming from the surface of each cell. Earthwork was also scheduled during the irrigation season so that construction water could be provided to the contractor, thus saving money.

Upon completion of the earthwork contract the structures and first round of well drilling work commenced. The structures work started just before the District's maintenance season when all of the canals are dewatered for maintenance. Well drilling was split into two contracts to see what flows could be produced by the first wells, and determine how many wells would be needed to meet the recovery flow rate goals. To finish the work, the second well drilling contract was let and then the well equipping contracts.

SUMMARY

In seven years, FID and Clovis were able to bring the Project from a conceptual study to a fully operational facility yielding new water supply. In just three years of limited operations, approximately 20,000 AF have been recharged between the facilities. California faces many political and environmental challenges and constraints along with an ever increasing competition for water. Projects like this, where agricultural and urban interests can partner together to develop new supplies will continue to be necessary in order to sustain urban growth and continue to meet the needs of the agricultural industry.

HEAVY EQUIPMENT OPERATOR TRAINING PROGRAM
OAKDALE IRRIGATION DISTRICT

Steven R. Knell, P.E.[1]
Derek L. Davis[2]

ABSTRACT

Oakdale Irrigation District (OID) is located in the upper portion of the San Joaquin Valley and provides irrigation and domestic water service to rural northeastern Stanislaus County. The OID's service area is comprised of 72,345 acres of which approximately 55,000 acres are irrigated farmland. The district has a staff of 68 employees working in all areas of operations, maintenance and construction.

A year ago, a near miss accident nearly killed one of its heavy equipment operators. That near miss accident prompted the district to evaluate its heavy equipment training program. That evaluation brought to light the need for more extensive training by all district operators. Being a skilled operator today entails many variables on a variety of equipment. Those skills need to be insured, tested and practiced to meet a standard of safety acceptable to the district.

OID put together a team of its most skilled operators, along with its Safety Coordinator, and tasked them with developing such a program. The result was the OID Heavy Equipment Operator Training Program. The Program is a combination of classroom learning, testing, practical field testing and hour certification criteria on 11 pieces of heavy equipment, inclusive of loaders, dozers, roller compactors, backhoes, excavators, graders and more.

The manual was reviewed by Operating Engineers Local No. 3 Union and highly praised for its completeness and thoroughness. It is based off of the National Center for Construction Education and Research (NCCER) using the latest in technology and training aid materials.

The following pages in this paper are directly taken from the Heavy Equipment Operator Training Manual. It is hoped these pages can give you a flavor of the detail provided in this training program and that you find a similar interest in how this manual may benefit your organization. As a promulgator for construction safety for all workers, OID encourages you to contact our offices for further information on this document or to contact OID for a copy.

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INTRODUCTION

Heavy equipment operators have opportunities for advancement within the Oakdale Irrigation District (OID) organization if they have the necessary talents, qualifications and training to support them. Construction work at OID is a team effort in which every person must do their job on time and in a professional manner. This means that all members of a construction crew must learn to work together and must develop interpersonal skills and good work habits.

A variety of heavy equipment is used on a construction site, especially in the site development phase of a project, when the site must be cleared and leveled and foundations dug. In many instances, demolition of existing structures must be done using heavy equipment before new construction can begin. In addition to construction work heavy equipment is used in canal maintenance, drain cleaning and reservoir maintenance

Take every opportunity to learn everything you can about the machines contained in this manual. The more you know about the machine, the better you will be able to handle it in any situation. Above all, be "Target Zero Safety Conscious". Don't just try to get a job done quickly; get it done correctly and safely.

OID asks that you keep an open mind to training and career opportunities. Learn all you can about how to do your job safely and effectively. You never know where your new skills can lead you.

EQUIPMENT OPERATOR I, II AND III – TRAINING PROGRAMS

Program Guidelines – Equipment Operator I

To complete this program and successfully advance through the levels of Equipment Operator I the candidate must successfully complete four program elements:

- Classroom training and written exams.
- Practical field task performance tests for each piece of equipment.
- Mentoring by senior operators and documented 500 hours of "seat time".
- Be subject to peer review before advancement to the Operator II position.

Classroom Training Candidates shall be required to read and understand the written material for each module of this program. The candidate will be required to take the open book chapter quizzes and then complete a closed book written exam and pass with a minimum score of 80%. Modules must be completed in the order listed in the program.

Practical Field Task Performance Tests Once a candidate successfully completes the classroom training portion of each module they are then eligible to take the practical field task performance test. Each piece of equipment has a field test associated with it. The field test represents the minimum required skills that a candidate must possess to begin to safely operate equipment.

Field tasks generally cover pre-start inspection, start up, moving and securing equipment, basic maneuvers and shut down. To pass the field test the candidate must demonstrate each task on the checklist to the satisfaction of the test administrator.

Documented Equipment Hours and Mentoring Each candidate will be required to document 500 hours of "seat time" for each piece of equipment in the training curriculum. A candidate can start to accumulate equipment hours on any piece of equipment for which they have completed the class room and field task tests.

As each operator begins to document equipment time he/she will be mentored by selected senior operators. A typical scenario would have a senior operator and an apprentice paired up on a job together. Mentors will have the duty to instruct, guide and report on the progress of their coworker. Mentoring will be an important part of the candidates training throughout the entire training program.

Peer Review Equipment operators are expected to be safety leaders on every job they work on. In many cases the operator must work with construction crews in close proximity to excavations, electrical lines, canals, and other hazardous locations. To be effective, Operators must assure on the job safety and have the confidence of the work crews on each jobsite.

When a candidate completes all of the elements of the Operator I curriculum and is ready to promote to the Operator II level he/she must receive a 2/3 majority vote of confidence from their coworkers.

Program Guidelines – Equipment Operator II

The ability to move into an Equipment Operator II position will be determined by three factors;

1. Successful completion of the Equipment Operator I curriculum
2. A 2/3rds majority vote of confidence by coworkers
3. A Board of Directors approved vacancy for an Equipment Operator II

Promotion into an Equipment Operator II position will begin the second phase of the Equipment Operator Program. That program has another series of equipment in which to become familiar and trained on. The steps and sequences of that training is identical to that required in the Equipment Operator I program with one exception, there is no Peer Review requirement in this program. It is assumed that the Equipment Operator at this level has demonstrated his safety skills and abilities to his coworkers, negating a second vote of confidence.

Equipment Operator III

Upon successful completion of the Equipment Operator II curriculum and upon certification of the required "seat time" for each piece of equipment, an equipment operator II will receive longevity increase in pay and receive the title of Equipment Operator III.

EQUIPMENT OPERATOR I TRAINING PROGRAM OUTLINE

Section 1- Heavy Equipment Safety

Classroom training based on NCCER Heavy Equipment Safety Module 22102-05.

- Chapter Quiz
- Written Exam

Section 2- Loader

Classroom training based on NCCER Loader Module 22205-06.

- Chapter Quiz
- Written Exam

Practical field task performance objectives based on NCCER Loader Module 22205-06.

- Complete proper prestart inspection and maintenance for loader.
- Perform proper startup, warm up, and shutdown procedures.
- Execute basic maneuvers with a loader; including proper movement and curling of the bucket.
- Carry out basic earthmoving operations with a loader; load a truck (to capacity if possible, and build a storage pile.

Note: Candidate shall obtain tanker endorsement within six months in order to drive a water truck.

Section 3- Dozer

Classroom training based on NCCER Dozer Module 22302-06

- Chapter Quiz
- Written Exam

Practical field task performance objectives based on NCCER module.

- Describe uses of a Dozer
- Identify the components and controls on a typical dozer
- Explain safety rules for operating a dozer.
- Perform prestart inspection and maintenance procedures.
- Start, warm up, and shut down a dozer.
- Perform basic maneuvers with a dozer, including moving forward, moving backward, turning with blade up, and straight dozing.
- Perform basic earthmoving, ripping and excavation operations with a dozer.
- Create a level pad approx. 20x20 feet.
- Push a stock pile while maintaining proper windrows.

Section 4- Roller Compactor

Classroom training based on NCCER Roller Module 22203-06.

- Chapter Quiz
- Written exam

Practical field task performance objectives based on NCCER module.

- Describe the uses of a roller.
- Identify the components and controls on a typical roller.
- Explain safety rules for operating a roller.
- Perform prestart inspection and maintenance procedures.
- Startup, warm up, and shut down a roller.
- Perform basic maneuvers with a roller.

Section 5- Backhoe

Class room training based on NCCER backhoe Module 22303-06 and Vista backhoe training program.

- Chapter Quiz
- Written exam

Practical field task performance objectives based on NCCER module and Vista training materials.

- Describe the uses of a backhoe
- Identify the components and controls on a backhoe.
- Identify accessories used on a backhoe.
- Perform prestart inspection and maintenance procedures.
- Start, warm up and shut down a backhoe.
- Perform basic maneuvers with a backhoe, including moving forward, turning, moving in reverse, and operating the front loading bucket.
- Perform basic earthmoving operations with a backhoe, including setting up backhoe, using stabilizers and digging with bucket. (Example: excavating a 30 foot. trench with spoil 2 feet. from edge)
- Proper tie down, transport, load and unloading procedures using Transport #33
- Demonstrate safety leadership skills; lead tailgate safety meetings, perform job hazard assessments and pre-task safety planning.

Note: Candidate must complete Trenching and Excavation Competent Person training by this level.

Section 6- Excavator (Kobelco 115)

Class room training based on NCCER training Module 22304-06 and Vista computer training program materials.

- Chapter Quiz
- Written exam

Field practical performance objectives based on NCCER and Vista materials.

- Identify components and controls on the excavator
- Explain safety rules for operating an excavator

- Describe and use accessories on an excavator.
- Perform prestart inspection and maintenance procedures.
- Start, warm up and shut down an excavator.
- Perform basic maneuvers with an excavator, including moving forward, moving backward, making a pivot turn, and making a spot turn.
- Perform basic earthmoving and excavation operations with an excavator. (Example: create a 10 x 10 foot excavation at least 4 foot deep.
- Perform proper loading, unloading, tie down and transport procedures using Transport #34.
- Demonstrate safety leadership skills; lead tailgate safety meetings, perform job hazard assessments and pre-task safety planning.

EQUIPMENT OPERATOR II TRAINING PROGRAM OUTLINE

Section 7- Transport #29

Classroom training based on JJ Keller," Cargo Securement Handbook for Drivers"

- Chapter Quiz
- Written Exam

Practical task performance Objectives

- Candidate shall demonstrate proper cargo securement techniques for a variety of heavy equipment.
- Candidate shall demonstrate knowledge of tie down equipment and load ratings.
- Candidate shall demonstrate safe driving techniques while carrying wide heavy loads.
- Candidate shall demonstrate safe maneuvering of transport trailer.
- Demonstrate safety leadership skills; lead tailgate safety meetings, perform job hazard assessments and pre-task safety planning.

Section 8 -Transfer Dump Truck

Classroom Training Based on NCCER Module 22202-06

- Chapter Quiz
- Written Exam

Practical Task Performance Objectives

- Describe the use and advantages of a transfer dump truck.
- Describe the types of dump trucks and their uses
- Describe the function and operation of the dump hoist, power takeoff unit, auxiliary axle, engine retarder, differential lockout, air brake system, and manual transmission.
- Demonstrate and steps of the pre-operational safety inspection.
- Perform the proper warm-up, operation, and shutdown procedure.
- State the duties and responsibilities of a dump truck operator.
- Identify the controls of a transfer dump truck.
- Safely operate a dump truck.

- Carry out basic operations with a dump truck; spot truck, unhook- dump-transfer- dump a load in a designated spot.
- Tailgate spread a load.
- Back up with a trailer attached to the dump truck.
- Demonstrate safety leadership skills; lead tailgate safety meetings, perform job hazard assessments and pre-task safety planning.

Section 9- Scraper

Classroom Training Based on NCCER Scraper Module 22204-06

- Chapter Quiz
- Written Exam

Practical task performance objectives based on NCCER module.

- Describe uses of a scraper
- Identify components and controls on a typical scraper.
- Explain Safety rules for operating a scraper.
- Perform prestart inspection and preventive maintenance procedures for scrapers.
- Start, warm up, and shut down a scraper.
- Perform basic maneuvers with a scraper. (Moving forward, backward, and turning).
- Carry out basic earthmoving operations with a scraper; pick up a load and hand it to a dump truck. Deposit approximately a 4-inch mat.
- Demonstrate safety leadership skills; lead tailgate safety meetings, perform job hazard assessments and pre-task safety planning.

Section 10- Heavy Excavator Kobelco 210 & 330

Prerequisite, Classroom training based on NCCER training module 22304-06 and Vista computer training program material.

- Chapter Quiz
- Written exam

Practical task performance objectives based on NCCER and Vista materials.

- Identify components and controls on the excavator
- Explain safety rules for operating an excavator
- Describe and use accessories on an excavator.
- Perform prestart inspection and maintenance procedures.
- Start, warm up and shut down an excavator.
- Perform basic maneuvers with an excavator, including moving forward, moving backward, making a pivot turn, and making a spot turn.
- Perform basic earthmoving and excavation operations with an excavator. (Example: create a 20 x 20 foot excavation at least 15 feet deep.)
- Perform proper loading, unloading, tie down and transport procedures using Transport #29.
- Perform advanced heavy lifting; use proper rigging and load chart to plan, lift and place a 12,000 lb pre-cast structure.

- Demonstrate safety leadership skills; lead tailgate safety meetings, perform job hazard assessments and pre-task safety planning.

Section 11- Grader

Class Room training based on NCCER Motor Grader Training module 22305-06.

- Chapter Quiz
- Written Exam

Practical task performance objectives based on NCCER module.

- Describe the uses of a motor grader.
- List types of motor graders and their uses.
- Identify the components and controls on a typical motor grader.
- Explain safety rules for operating a motor grader.
- List accessories used on a motor grader.
- Perform prestart inspection and maintenance procedures.
- Start, warm up, and shut down a motor grader.
- Perform basic maneuvers with a motor grader, including moving forward, moving backward, and turning.
- Perform basic earthmoving maneuvers with a motor grader.
    1. Grade a rough grade by following grade stakes placed along a 300-foot section, which is at least double the width of the machine.
    2. Demonstrate rotation of the blade for high-bank grading.
    3. Cut a V ditch with a 3 to 1 slope.
    4. Grade 100 foot road with 3% slope at least double the width of the machine.

Section 12- Boom Truck

Class Room training by OID approved Boom Truck Training Program Provider

- Chapter Quiz
- Written Exam

Practical Task Performance Training Objectives

- Ability to use load charts to plan lift.
- Ability to investigate a site and then properly configure and set up a boom truck.
- Understand ideal conditions assumed by a crane load chart and the ability to make appropriate reductions in capacity when conditions are less that ideal.
- Knowledge and understanding necessary to follow crane safety rules and regulations.
- Ability to select and use proper rigging, accessories and identify defective rigging.
- Knowledge, understanding and ability to follow proper maintenance and inspection procedures.

ACKNOWLEDGEMENTS

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HARDING DRAIN WATERSHED AGRICULTURAL AND URBAN IMPACTS — EVALUATION, EDUCATION AND OUTREACH

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ABSTRACT

Harding Drain is a constructed agricultural drain that carries flows from both agricultural and urban sources. The drain and downstream waterways have been listed as “impaired” for a variety of constituents. However, much has changed within the watershed since it was included on California’s 303(d) list. Though various programs have previously collected water quality data they did not provide a comprehensive, clear picture of how water quality is linked to sources, or a clear understanding of what strategies might be effective in controlling the various constituents causing the impairment.

TID applied for and was awarded a grant to address these issues. The goals of the program were to: (1) Provide an assessment of water quality in the Harding Drain watershed and impacts on the San Joaquin River; (2) Educate stakeholders about conditions, causes of impairment, and management practices that may be available to address water quality concerns; and (3) Engage stakeholders in developing a Watershed Management Plan to address water quality issues within the watershed. The project, implemented over a three year timeframe, assisted local stakeholders in understanding how the watershed functions, the current conditions within the watershed, and how their activities may be influencing water quality.

The project involved a watershed assessment, water quality monitoring program, data analysis, and identification of management strategy recommendations with involvement and input from engaged local stakeholders. Education and outreach activities were conducted in both the agricultural and urban sectors, through workshops, newsletters, a website, and a variety of activities including stormdrain stenciling, education seminars for teachers, and farm-site consultations. The resulting watershed management plan includes a clear understanding of current conditions, identifies problems areas, as well as measures available to address these issues. Utilizing this plan will enable stakeholders to continue to work together to address the remaining water quality issues, in an effort to avoid future regulation.

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INTRODUCTION AND BACKGROUND

Purpose and Scope of the Harding Drain Watershed Grant

The Harding Drain Watershed is a complex, managed water system in the San Joaquin Valley of California, comprised mainly of man-made water conveyance facilities within the Turlock Irrigation District's (TID) boundaries. The watershed encompasses approximately 100,000 acres of land used for agricultural (83%) and urban (17%) purposes. The Harding Drain is an unlined constructed agricultural drain which collects and conveys water from a variety of sources and ultimately discharges to the San Joaquin River. Figure 1 below shows the general location of the Harding Drain Watershed.

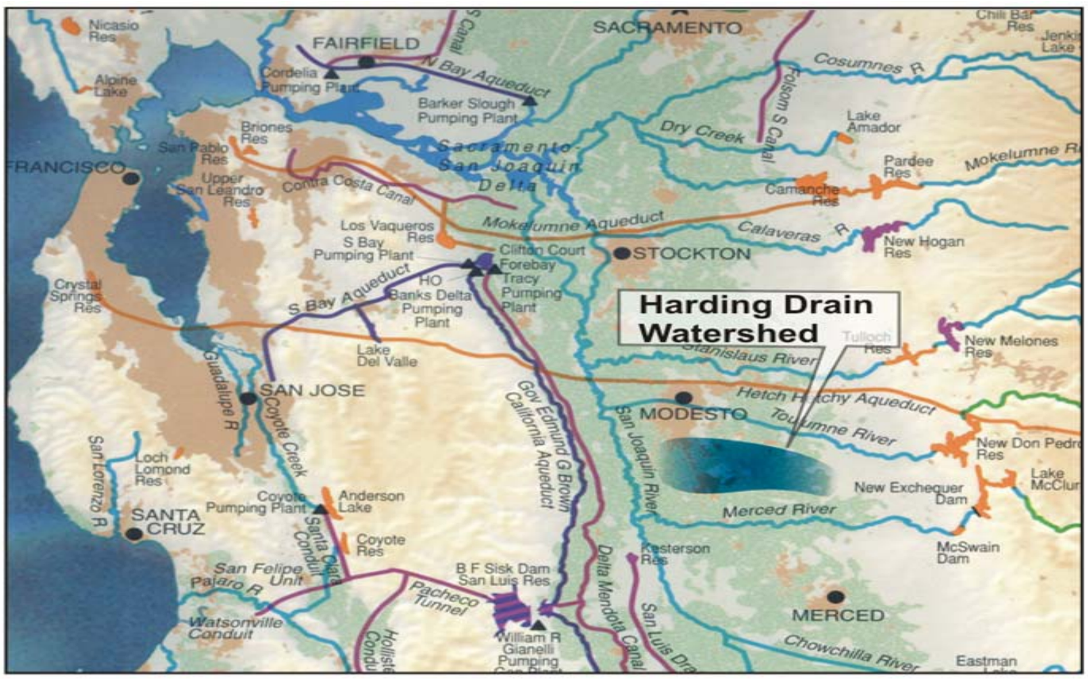

Figure 1. Location of Harding Drain Watershed (Brown and Caldwell 2008a)

Based on data gathered in the late 1980's and early 1990's, the Harding Drain was characterized as water quality limited for ammonia, unknown toxicity, diazinon and chlorpyrifos, leading to its inclusion on the Clean Water Act (CWA) Section 303(d) list of impaired waterways in 1998.[3] The listing is a first step in a regulatory process, prescribed by the CWA, designed to improve conditions within water quality limited waterways and bring them into compliance with water quality standards.

Local watershed based efforts can be successful in addressing water quality issues, eliminating the need to implement a formal regulatory process. Significant changes within the Harding Drain Watershed since the 1980's has resulted in water quality improvements. In an effort to understand the current conditions, TID began gathering

[3] USEPA 2008. United States Environmental Protection Agency. Total Maximum Daily Loads website. Listed Water Information, Cycle: 1998.

data in 2001 on three of the four listings (i.e. diazinon, chlorpyrifos and ammonia) which showed that improvements had been achieved. An analysis of the data was provided to the State Water Resources Control Board (SWRCB) in the 2006 listing process, resulting in the removal of diazinon and ammonia from the 303(d) list. The Harding Drain remains listed for chloryprifos and unknown toxicity.

In a parallel effort to address these issues, TID applied for and was awarded a $1.4 million dollar Proposition 50 grant from the State of California. The resultant project included components designed to: (1) Provide an assessment of water quality in the Harding Drain watershed and impacts on the San Joaquin River; (2) Educate stakeholders about conditions within the drain, causes of impairment, and management practices available to address water quality concerns; and (3) Engage stakeholders in developing a Watershed Management Plan to address water quality issues within the watershed. The grant funded project, began in June 2005 and was completed in December 2008.

Watershed Description and Land Use Assessment

The Harding Drain Watershed is not a typical watershed. It is a unique system of man-made irrigation canals and laterals, pumps, pipelines, creeks and drains. For this reason, it cannot be defined based simply upon topography. As a result, the project defined the approximate boundaries of the watershed based upon the system configuration as well as topography.

The Harding Drain Watershed area is comprised predominately of agricultural lands. The actual size of the watershed varies seasonally. During the non-storm season, also commonly referred to as the irrigation season, the watershed includes approximately 95,000 acres. During the storm season, an additional 14,000 acres drain into the watershed from upslope areas including Sand Creek. Overall, agriculture accounts for approximately 83 percent of the land uses during the irrigation season, while the remaining 17 percent are made up of urban areas including the communities of Turlock, Hughson, and portions of Ceres, Keyes and Denair. The predominate crops grown within the watershed include nearly 34% orchards (i.e. almonds, walnuts, peaches and nectarines), 20% corn, and 15% pasture or alfalfa. The remaining 14% of agricultural land includes a variety of dairies, farmsteads and poultry farming operations, and is used to produce a variety of field crops including beans, sweet potatoes, and sudan, as well as vineyards, and nursery crops.

TID was the first irrigation district established within the State of California. In the late 1800's TID built a system of gravity-fed canals to convey water from the Tuolumne River to local farms for irrigation. Drains were then built to transport spills from the canal system to local rivers. The Harding Drain is a constructed, earthen agricultural drain designed for that purpose. The majority of the watershed is located within TID's irrigation boundaries.

The inflows to this system of canals and drains have evolved over time. With the advent of electricity, wells were installed to supplement surface water supplies and lower groundwater levels to facilitate crop production. As urban areas developed on what once were agricultural lands, urban runoff from storm events and dry-season flows were routed to the canal system. Wastewater effluent from the Turlock Regional Water Quality Control Facility were conveyed and discharged into the Harding Drain for transport to the San Joaquin River.

As a result, in addition to planned irrigation flows during the irrigation season (generally mid-March through mid-October) the canal system now conveys urban runoff (either dry-weather runoff or storm water), tile drainage, irrigation return flows from "spill ditches" (irrigation pipelines that flow back into the canal), and drip/micro flush systems. The quantities of these additional flows, compared to planned irrigation supplies, are generally extremely small. However, these other inflows are unplanned, and typically contribute to the volume of water spilling from the canals to the drain.

During the non-irrigation season (generally mid-October through mid-March) flows into the canals may include storm water or dry-weather flows from urban areas, storm water from Sand Creek, tile drainage and groundwater drainage from pumps.

Any flows from the system of canals within the watershed, not used for irrigation, spills to the drain. In addition, the Harding Drain also conveys treated effluent from Turlock Regional Water Quality Control Facility. During the non-irrigation season flows within the drain are typically dominated by wastewater discharges. The exception being during significant storm events, when storm water flows overwhelm other inflows. Groundwater seepage, agricultural runoff, and runoff from local roadways are also able to flow into the drain.

Canal operation can play a role in the flows within the drain. Water typically flows through the TID system from the northeast to the west and southwest; however, flow routing varies seasonally. During the irrigation season, canals are operated to deliver irrigation water and minimize spills. During the non-irrigation season, flow routing can vary from day-to-day and month-to-month. The canals are operated to route flows in one direction or another, depending on flow conditions and system needs for flood control or system maintenance.

Given the variable nature of the system operation, water can flow to the Harding Drain from a variety of sources and inputs at any given time. These conditions provided challenges for characterizing water quality and associating water quality impacts with potential sources. A complete description of the watershed, land uses, hydrology and historic water quality data (described below) are contained within the Baseline Watershed Assessment Report developed for the grant project.

Existing Conditions Assessment

One of the first steps in the grant project included evaluating the existing conditions within the drain. Historic data was compiled and reviewed to: (1) Establish baseline conditions for constituents to be monitored under the grant program; (2) Assess spatial variability and effects of upstream sources; and (3) Analyze temporal variability (e.g. both seasonally and year-to-year).

The existing data review focused primarily on general water quality conditions and constituents of concern that were anticipated to be monitored under the grant project, and to specifically address the 303(d) listings (i.e. diazinon, chlorpyrifos, ammonia, and unknown toxicity). Since the source of the toxicity was unknown, many potentially toxic constituents were evaluated. A secondary focus was on other constituents that are of downstream concern including nutrients, organic carbon, and indicator bacteria.

Several sources of data were evaluated including water quality monitoring data from TID, the City of Turlock, the Central Valley RWQCB Surface Water Ambient Monitoring Program (SWAMP) and Total Maximum Daily Load (TMDL) bioassessment program, a Draft Use Attainability Analysis prepared for the SWRCB for the drain, the Department of Pesticide Regulation (DPR) Surface Water Monitoring Program, and the United States Geological Survey (USGS) National Ambient Water Quality Assessment (NAWQA) program. Data from these programs included field parameters, conventional laboratory analytes, pathogen indicator bacteria, trace metals, pesticides, and toxicity. Flow was also evaluated to help determine the relative contributions of various inputs into the watershed.

A compilation of the data showed that information was available for general water quality constituents in the Harding Drain, such as salinity, nutrients, temperature, and pH. However, data for other constituents, particularly pesticides and toxicity, were spatially and temporally limited. As a result, the grant funded monitoring program was designed to address these data gaps.

Monitoring Program

Approximately $900,000 within the grant were allocated to developing and implementing a water quality monitoring program over approximately two years. The goal of the program was to characterize water quality within the watershed, and identify water quality problems and their potential sources. The challenge was to gather as much data as possible to accomplish this task over a relatively limited timeframe, and within a limited budget. While the overall dollar amount seems large, some of the laboratory analyses, particularly toxicity testing, can be extremely expensive and inconclusive. As a result, it was important to prioritize the monitoring effort to maximize the information gathered. To achieve these goals a comprehensive yet adaptive program was designed.

The land use evaluation completed in the Watershed Assessment Report was used to characterize conditions within the watershed and identify the types of sources having the potential to influence water quality. Generally, these include urban runoff, wastewater effluent, agricultural runoff and groundwater. The monitoring program was then designed to help characterized these potential influences.

A pesticide use analysis was completed to focus monitoring efforts on those pesticides that had the most likelihood of being present within the drain, and those that had the highest potential to cause toxicity. DPR data from 2000-2004 was analyzed to assess pesticide use within the watershed (CalPIP, 2000-2004). The three factors used to prioritize the list of pesticides for the final monitoring program included pesticide use characteristics (i.e. total acres treated, total pounds applied and frequency of application), the potential to cause toxicity, and the pesticide's persistence in the environment.

Many laboratory analyses provide data for multiple active ingredients within a family of pesticides, from one laboratory test method. As a result, priority pesticides were grouped into pesticide families, and test methods were identified to provide the most data, at the least cost. In total, 60 different pesticides or pesticide "active ingredients" were sampled and analyzed throughout the monitoring program.

Another primary goal of the monitoring effort was to address the unknown toxicity listing by determining if toxicity remains a concern, and evaluating potential sources. Unfortunately the science behind identifying the source of toxicity is not as clearly defined as one would like. Once toxicity is identified, a series of tests are conducted to essentially remove various types of pollutants from the water sample and the water is retested for toxicity. This "process of elimination" approach provides a means of helping to pinpoint the potential cause. Each test, however, can be quite expensive. As a result, the monitoring program was designed to facilitate the use of the laboratory analyses for pesticides and metals (both potential toxicants) to help focus follow-up toxicity evaluations.

Monitoring sites were selected based upon local hydrology, preliminary results from the land use assessment, knowledge of the various inflows within the system, and the review of existing data. Wherever feasible, sampling locations utilized sites from previous monitoring efforts to provide a more extensive data set. Sampling locations were generally grouped into two categories: (1) sites located along the drain itself, and (2) sites that discharged to the drain or were further upstream in the watershed. The program ultimately included three sites along the drain, six sites representing discharges to the drain, and seven sites within upstream areas of the watershed, for a total of sixteen sampling sites. A detailed Monitoring Plan and Quality Assurance Project Plan (QAPP) were prepared to document to monitoring approach and quality assurance processes designed to ensure the accuracy of the data gathered.

Between May 2006 and May 2008 each of the sixteen sites (see Figure 2 below) were monitored monthly (with the exception of the wastewater effluent inflow, which was added part of the way through the program) for a variety of constituents. In addition, organophosphorus pesticide samples were collected at the three sites along the drain in April, May, June, and July to assist in further characterizing Chlorpyrifos concentrations within the drain, due to the 303(d) listing.

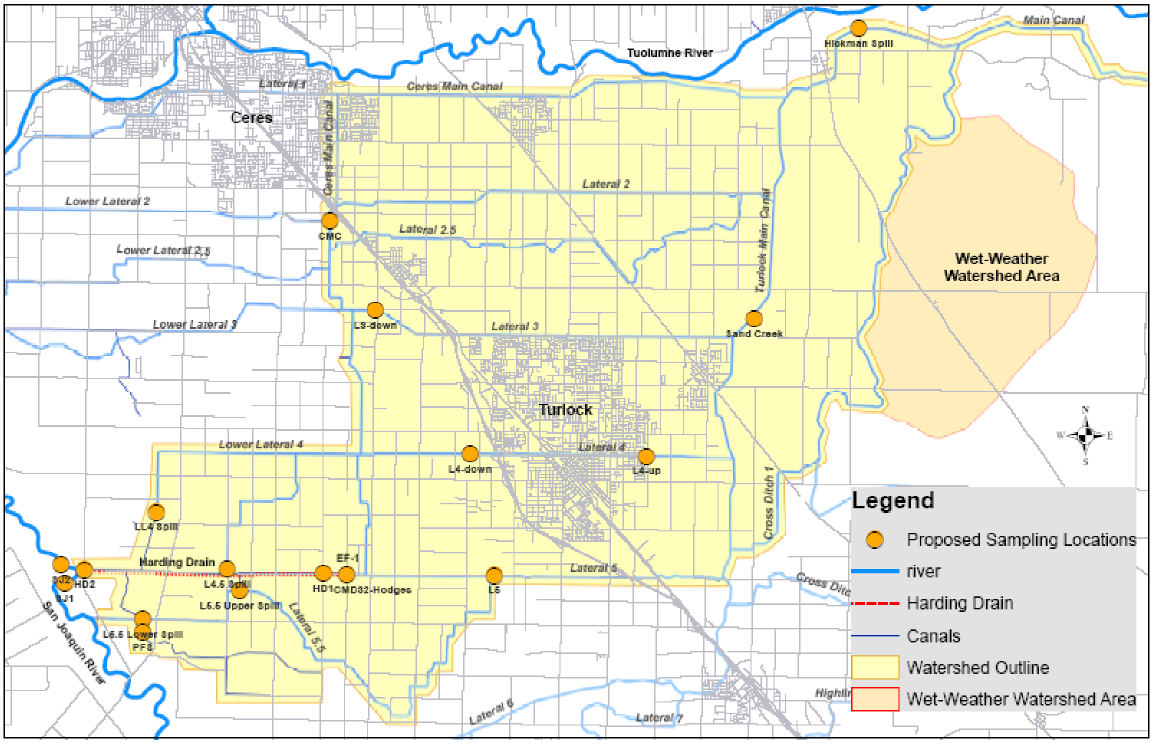

Figure 2. Harding Drain Watershed Project Monitoring Sites.

The final monitoring program included various field parameters [4], conventional laboratory analytes [5], *E. coli*, trace elements [6], pesticides [7] and toxicity. Field parameters, conventional laboratory analytes, and trace elements were monitored throughout the watershed, while the toxicity analyses and the majority of the pesticides were only analyzed at sites along the drain. *E. coli* samples were collected and analyzed along the drain at first, with additional sites included later in the monitoring effort. This approach of prioritizing monitoring constituents and locations was designed to maximize the amount of data gathered to characterize conditions within the drain, as well as the potential influences from various land uses within the watershed to enable the development of a management plan to address problems identified.

[4] Field parameters monitored during the project include: dissolved oxygen, temperature, conductivity, turbidity, ammonia, pH and flow.

[5] Conventional laboratory analytes monitored during the project include: ammonia, nitrate, nitrite, Total Kjeldahl (TKN), total phosphorus, total organic carbon (TOC), dissolved organic carbon (DOC), total suspended solids, total dissolved solids (TDS), and color.

[6] Trace elements refers to metals (copper, zinc, cadmium, lead and nickel), as well as non-metals (boron) and metalloids (selenium and arsenic).

[7] Pesticides families monitored during the project include: organophosphorus, synthetic pyrethroids, carbamates, urea, dithiocarbamates, organochlorine, triazine and chlorinated herbicides. Individual pesticides monitored were propargite, pendimethalin, oxyfluorfen, paraquat, cis 1,3-dichloropropene, trans 1,3-dichloropropene, glyphosate, trifluralin, molinate, and thiobencarb.

Monitoring Data Analysis

Monitoring data collected between May 2006 and July 2008 was evaluated to characterize the current conditions within the watershed. This process included entering the data into a SWAMP compatible database. The electronic database was then used to generate tables and graphs to facilitate easier data analysis, including a comparison to reference values [8] and historical data. The data review was compiled in the project's Data Evaluation Technical Memorandum.

In most cases, a three-tiered graphical representation of the data was developed to assist in visualizing and analyzing the dataset. The three-tiered graphs depict the laboratory results at monitoring sites along the drain (Tier 1 Harding Drain), sites immediately upstream of the drain (Tier 2 Downstream) and sites further upstream (Tier 2 Upstream). Arrows were used to show where the inflows from Tier 2 Downstream sites discharge to the drain, to assist reviewers in evaluating potential impacts from upstream sources on downstream water quality (Brown and Caldwell, 2008b). Figure 3 illustrates the three-tiered graphs described above.

When limited data was available (e.g. when a limited number of detections were found for a particular pesticide active ingredient), tables were used to present the monitoring results.

The purpose of these analyses was to show the current conditions within the drain, and to qualitatively evaluate whether or not conditions within the drain have changed over time. The information presented included a description of the magnitude of the detected data, the temporal variability and seasonality of the data, along with a comparison to historic conditions, and an indication as to the potential water quality implications associated with each constituent.

The historic data previously compiled in the Watershed Assessment Report and the City of Turlock's National Pollution Discharge Elimination System (NPDES) permit data were used to provide the historical perspective. In most cases, an indepth statistical analysis of the current data compared to the historic data was not performed due to limited availability of historic water quality data and time constraints. However, where applicable, some statistical comparisons were performed.

Toxicity testing was included in the monitoring program and was performed on *Pimephales promelas* (fathead minnow), *Ceriodaphnia dubia* (daphnid) and *Selenastrum capricornutum* (green algae). Results showed no significant toxicity to fathead minnow or *C. dubia,* even though historic data for these species resulted in the unknown toxicity listing. There were, however, several sampling events where reductions in algal growth occurred when compared to the laboratory control. Several toxicity identification

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[8] For the purposes of determining appropriate detection levels and interpreting analytical results, reference values were compiled, using representative water quality goals from a variety of sources. In many cases, the values used are not established water quality objectives, receiving water limits, or other regulatory criteria.

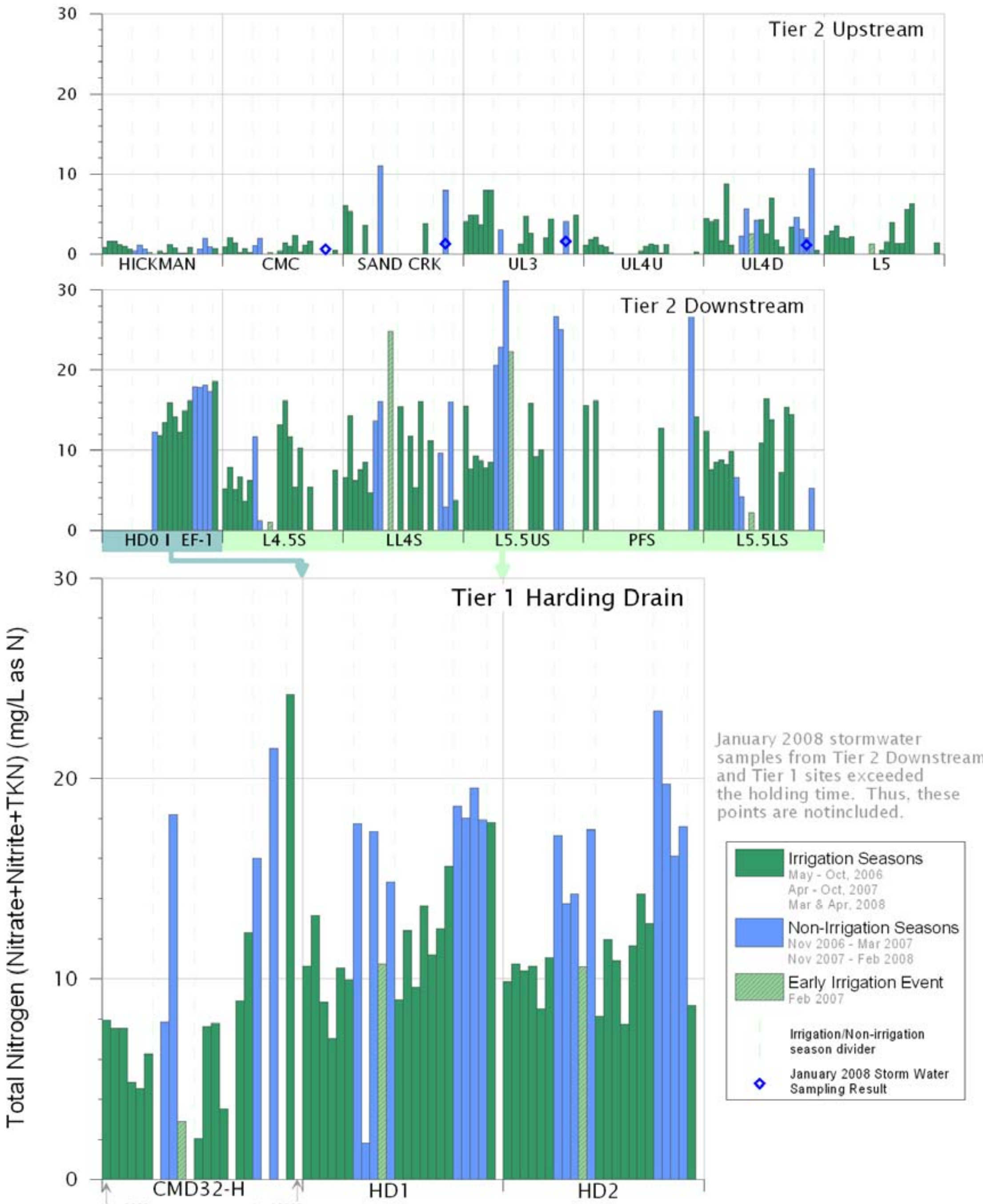

Figure 3. Three-Tiered Graph for Total Nitrogen (Brown and Caldwell 2008b)

evaluations (TIEs) were performed in an attempt to determine the cause of the toxicity, but no specific toxicants were identified as a result. The algae toxicity analysis presented significant challenges in interpretation of the data and often led to more questions than answers. Some of the challenges encountered were related to data interpretation, cellular adhesion of algae to the flask wall altering the algae counts, and variations allowed in the test methods which can also impact the results. In an attempt to resolve these issues, numerous split samples were sent to two and sometimes three different labs, and grant funded sampling was coordinated with the City of Turlock's NPDES permit sampling. Unfortunately these efforts provided no clear resolution. As a result of the uncertainty related to the algae toxicity results, it was described as "unconfirmed" algae toxicity within the reports. (Brown and Caldwell, 2008b)

Overall, although there was an extensive list of constituents monitored through the Harding Drain Watershed Project, only a limited number of them were detected. Even fewer constituents were found at levels that exceeded reference values. The analysis of the data gathered through the program resulted in identification of specific priority constituents. This relatively short list includes pesticides, salinity, nitrogen, phosphorus, *E. coli*, dissolved organic carbon (DOC), copper, zinc and unconfirmed algae toxicity.

Education and Outreach

An extensive education and outreach program was implemented throughout the project. Education and outreach activities were designed to: (1) develop a mutual understanding amongst stakeholders regarding the watershed conditions, what may be impacting water quality, and best management practices available to address problems identified; and (2) provide various segments of the public with information regarding the potential impacts from land use practices and management practices available to reduce those impacts. To accomplish this task, various programs were initiated including establishing a Watershed Advisory Committee, hosting and participating in educational workshops, developing articles for local newsletters, posting information on the internet, and providing onsite consultations for local growers.

A Watershed Advisory Committee was formed to assist with the project, and ensure that the final product was both meaningful and implementable. Stakeholders representing a variety of agricultural and urban interests participated in the process. Quarterly meetings provided a forum to develop a mutual understanding of: the watershed and its various land uses; historic water quality conditions that led to the 303(d) listing of the drain; inflows into the watershed and how they may impact water quality; how flows are routed through the watershed; the water quality conditions and their potential implications; as well as the potential actions available to address water quality concerns. The ultimate product of this process was a Watershed Management Plan (described below), designed to guide long-term water quality improvements. The Watershed Advisory Committee also provides a forum for continued coordination and implementation of the Management Plan moving forward.

A variety of educational workshops were conducted during the project. Each was tailored to the audience, with many designed in a manner such that local agencies could continue to provide similar education and outreach opportunities in the future. Some workshops provided education to the growers within agricultural community, while others reached out to urban pesticide applicators or suppliers, and agricultural pest control advisors.

Urban Education and Outreach. The project helped to educate retailers which sell pesticides in the urban setting using the "Our Water – Our World" program[9]. Several stores within the City of Ceres participated in employee training sessions, and now have information and fact sheets readily available to customers regarding less toxic, more environmentally friendly alternatives. The City of Ceres will maintain the program as a part of their storm water protection activities. In the City of Turlock, a storm drain stenciling program was initiated, including the development of door hangers and fliers describing simple things homeowners can do to save water and reduce urban runoff. This program will also provide ongoing education and outreach within the watershed.

Additionally, the project assisted the cities of Ceres and Turlock, Stanislaus County, and the Friends of the Tuolumne in hosting an educational seminar for elementary school teachers. Local teachers received hands-on training, educational curriculum activities and other information regarding watersheds, water quality and the hydrologic cycle to incorporate in the classroom. By educating local school children about where water comes from, where it goes to, and the activities that impact water quality and the environment, members of the community will begin to develop a deeper understanding about the need to protect and preserve this precious resource.

Agricultural Education and Outreach. An educational program was designed for local growers utilizing the services of local pest control advisors (PCAs). PCAs are the experts that growers rely upon to identify the best methods for controlling pests and as such were the ideal avenue for reaching out to local growers to evaluate existing agricultural management practices and identifying measures available to reduce water quality impacts. The on-site consultation program used during the project was based upon a similar program implemented on the west side of the San Joaquin Valley by the Coalition for Urban and Environmental Stewardship (CURES). Although this portion of the project was slow to start, it was well received by the PCAs and their customers.

During the project local PCAs worked with their customers, asking questions about activities and facilities on a specific farm. PCAs then used that knowledge to suggest additional actions which would meet the individual grower's needs while providing additional water quality protection. Management practices discussed, in the form of a survey, included pesticide application methods and sprayer calibration, nutrient management, tank filling procedures, laser leveling, vegetative ditches, tailwater return systems, and water quality training availability. A follow-up survey was scheduled 8 to 12 months later to review the changes, identify which recommendations worked, and suggest others if necessary. Overall, the follow-up surveys indicated an increase in understanding of water quality issues and related best management practices (BMPs). The follow-up survey showed an increase in management practice implementation of 3% to 40% from the earlier survey, with an average increase over all areas of 7%.

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[9] Our Water – Our World. 2008. http://www.ourwaterourworld.org

Watershed Management Plan

Knowledge of land uses and inflows into the watershed from the Watershed Assessment Report (described above) was used, in combination with the data gathered during the monitoring program and illustrated in the Data Evaluation Technical Memorandum to evaluate potential sources contributing to the water quality concerns. This information was then incorporated into the final product of the grant project, a Watershed Management Plan.

The Watershed Management Plan was designed to: describe conditions within the watershed, identify water quality concerns, and focus future actions to improve conditions including, but not limited to the removal of the remaining CWA 303(d) listings. Though an extensive list of constituents was monitored during the project, only a limited number were detected or found at levels that exceeded reference values. The TID, its consultants and the Watershed Advisory Committee reviewed data gathered during the monitoring portion of the program to focus on a list of priority constituents addressed by the Watershed Management Plan. The criteria used to select the top priority constituents included downstream CWA 303(d) listings, monitoring data exceedances of reference values, and the availability of potential mitigation measures to address the issue. The highest priority constituents identified through this process were chlorpyrifos and other pesticides, salinity, unconfirmed algae toxicity, nutrients (i.e. nitrogen and phosphorus), drinking water constituents (i.e. *E. coli* and dissolved organic carbon), and metals (i.e. copper and zinc).

Next, a suite of management measures or strategies were identified, to provide a range of options that could be drawn upon to address water quality concerns. The strategies identified included both management practices and targeted actions.

Management practices identified in the Watershed Management Plan generally focused on source control opportunities and structural treatment options. Practices ranged from the relatively simple to more complex, including drainage modifications, detention basins, vegetative practices, tailwater return systems, as well as large scale crop or irrigation practice changes.

Targeted actions were other measures available to improve water quality or better characterize conditions and sources. Targeted actions included ongoing monitoring to assess water quality improvements, further evaluating sources to focus water quality improvements (i.e. salinity and *E. coli*), and activities to resolve the various issues surrounding the algae toxicity test methods.

Overall, an adaptive approach to improve water quality within the Harding Drain Watershed was recommended. Early, cost-effective and achievable actions were identified for both agricultural and urban influences to address the priority constituents, along with continued monitoring to measure progress and determine if more costly actions are needed to achieve water quality goals. Additionally, it was recognized that the measures included in the plan are a current listing of options identified during the project. However, additional measures may be available or become available over time.

To reduce duplication of efforts and focus activities, it was recognized that existing and ongoing regulatory programs and activities provide a logical starting point. Many of these programs are in their infancy, and as a result, the water quality improvements anticipated from these activities have not yet been realized. Examples of these programs include: the Irrigated Lands Regulatory Program (CVRWQCB 2003), the Confined Animal Facility Program for dairies (CVRWQCB 2007), and the Urban MS4 NPDES Program for urban stormwater and dry-season runoff (USEPA 2005, CVRWQCB 2001).

It is important to note that in addition to the existing regulatory programs, ongoing voluntary efforts are being implemented which are expected to result in water quality improvements. CURES, established in 1997 to promote rural and urban stewardship of the environment, has implemented several programs to support agriculture in improving practices to protect water quality, including development of a BMP Handbook, on-site assessments and sprayer calibration programs. Most recently, CURES developed a conceptual approach for growers, using flow charts, to help select the most appropriate BMPs to reduce potential impacts to water quality from agricultural practices.

Additionally, the City of Turlock is working on plans to relocate the wastewater discharge from the drain directly to the San Joaquin River. Removing all or a portion of those flows will influence both the volume and concentrations of constituents of concern within the drain including nutrients, salinity, organic carbon, metals and unconfirmed algae toxicity, particularly during the non-irrigation season. As a result, monitoring is recommended after the facility modifications are made to assess the conditions at that time. Modification to the management actions can then be evaluated and addressed as needed.

The plan recommends that as these existing activities are implemented, progress made toward meeting water quality goals be monitored and evaluated to determine the need, if any, for additional actions. This is particularly important for the CWA 303(d) constituents. Data will be needed to show improvements have been obtained, and provide the evidence necessary to pursue delisting.

It is envisioned that the watershed-based stakeholder process will provide a forum to facilitate and evaluate the improvements identified within the plan. The Watershed Advisory Committee provides for continued communication and coordination amongst stakeholders. This process will enable sharing of information and consideration of projects to address constituents of concern should the early and ongoing actions need to be supplemented by additional measures to achieve the desired results.

SUMMARY

Overall, the grant project was extremely successful. It enabled a thorough review of the current conditions and provided a forum for stakeholders within the watershed to get involved early and assist in resolving water quality issues. The resulting Watershed Management Plan, and its supporting documents, will provide a basis for local stakeholders to continue to work together toward water quality improvements.

If water quality concerns continue, the RWQCB will dictate actions needed to resolve the impairments, as specified by the CWA. It is hoped that this project has provided a framework for working together as a watershed to address these issues before regulatory action is needed. Many times a local remedy may be easier to implement than one dictated by others.

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