Irrigated Agriculture Responds to Water Use Challenges — Strategies for Success

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Preface

The papers included in these Proceedings were presented during the **USCID Water Management Conference**, held April 3-6, 2012, in Austin, Texas. The Theme of the Conference was ***Irrigated Agriculture Responds to Water Use Challenges — Strategies for Success.*** An accompanying book presents abstracts of each paper.

Texas has the third largest irrigated area in the U.S. (more than six million acres) and the tenth most surface water deliveries to irrigation (nearly 2.4 million acre-feet). The state faces the same type of challenges and pressures on water supply, drought conditions, permitting and regulatory issues, irrigation district management and urbanization as the rest of the western U.S. By the same token, there are numerous opportunities for the irrigation industry to lead the way in future water management activities and policies.

The Conference provided a forum for presentation and discussion of these issues and others. The Texas venue allowed participants to collaborate and learn about similarities and differences in irrigation issues and strategies between the traditional USCID conference base in the western U.S., and those in Texas.

The authors of papers presented in these Proceedings are professionals from academia; international, federal, state and local government agencies; water and irrigation districts; and the private sector.

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

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Conference Chair

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ABSTRACT

Current efforts in water conservation and irrigation efficiency illustrate the need for modern data management systems that that can consume, validate, calculate, manage and automate the reporting of real-time and historical water data with ease. Managing the vast amounts of data being collected along with the ability to dynamically link to water resource management models, are key requirements for irrigation districts. The problem presented in this paper is the availability of Commercial Off-The-Shelf (COTS) solutions that provide a stable decision support platform for water conservation and irrigation efficiency efforts while offering additional capabilities in the areas of environmental monitoring and energy production. The Turlock Irrigation's approach to solving this problem is based on WISKI: a comprehensive COTS solution that manages and automates the entire process of data collection, import, validation, editing, reporting, and exporting with advanced editing capabilities. The KISTERS WISKI (**W**ater **I**nformation **S**ystem **KI**STERS) solution can integrate with all in-house data collection systems, including water resource management models and offers users a wide range of tools for water data management. Automation of the routine data management tasks performed by District staff reduces the lag time between data collection and decision-making, thus increasing their overall operational efficiency. Streamlining the entire process from data collection to reporting in one solution has also improved the District's ability to conserve water and focus on revenue generating opportunities like energy production. WISKI makes information available in near real-time to District staff, thereby reducing the amount of time and money spent generating good data for decision-making. The use of cumbersome and error-prone spreadsheets, as well as custom in-house developed data management solutions have been phased out as COTS solutions like those from KISTERS offer a viable alternative without the hassle. Without a solution like WISKI, that accommodates all the District's interests, in addition to saving its engineers and hydrologists valuable time and money, the District would not be as efficient as it is today.

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INTRODUCTION

Integrated water management of both surface and ground water has become an important concept in the management of this precious natural resource. The proper management of water resources requires a well defined monitoring program that includes the collection, analysis, reporting and overall management of water quantity and water quality data.

Processes and programs for data collection have been well defined over the past 50+ years, and there are many public and private agencies meeting this segment of the data management process. However, effectively converting the massive amounts of data being collected into usable and actionable information for decision-making purposes has been limited to only a handful of private and public agencies around the world. Prior to the 1990's, only government agencies could afford the investment in time and money required to develop robust data management systems capable of handling the volumes of data being collected. Even at that, the majority of systems being developed were limited in scope and capability due to the agency's specific focus. It was not until the 1990's that private consultants started investing in the development of data management systems at the request of government agencies needing to replace their aging, limited capability, "homegrown" solutions. Some of these consultants recognized a need to develop a commercial "off-the-shelf" (COTS) data management system and designed a business model around this niche industry. As computer and monitoring technologies have rapidly progressed in complexity, and others have retired from industry, several data management solutions have fallen by the wayside and are no longer viable options for organizations. Today there are a limited number of entrepreneurs that have survived and provide excellent systems for water data management.

Most current systems on the market today can store vast quantities of data. However, the key to a comprehensive data management solution is the ability to capture and ensure a high level of data quality while maintaining an efficient flow of data to decision-makers. The solution to achieving this high level of data quality is to provide an integrated system that takes title of the data from the initial import of raw data to the export of quality processed data. Only a few solutions meeting these criteria exist in the world today. The desirable solution must also be able to meet the stringent requirements and policies of the Federal, State and Local agencies. In addition, organizations are requiring that the COTS systems be delivered and configured in a minimal amount of time, flexible enough to manage all their data, and not require ongoing consulting and support from the provider to be able to maintain it.

This paper discusses the need for a comprehensive data management solution that can perform a host of tasks: collect, validate, calculate, manage, and report real-time and archived data; integrate with existing applications like water resource management models; provide a decision support platform for water conservation and irrigation efficiency; monitor diverse inputs from environmental to energy production parameters; and provide the scalability to serve the data management needs of both small and large organizations alike. Along with the discussion for the need of a comprehensive data management system, this paper presents Turlock irrigation district's use of WISKI

(Water Information System KISTERS) as their comprehensive data management solution and decision making platform.

TURLOCK IRRIGATION DISTRICT COMPANY PROFILE

Established in 1887, the Turlock Irrigation District (TID) was the first publicly owned irrigation district in the state and is one of only four in California today that also provides electric retail energy directly to homes, farms and businesses

Since 1923, TID has been providing safe, affordable and reliable electricity to a growing retail customer base that now numbers in excess of 98,000 residential, farm, business, industrial and municipal accounts in an electric service area that encompasses 662 square-miles in portions of Stanislaus, Merced, Tuolumne and Mariposa counties.

TID provides irrigation water to more than 5,800 growers in a 307 square-mile service area that incorporates 149,500 acres of Central Valley farmland. The District has been delivering irrigation water to growers since completing its gravity-fed water conveyance system of canals and laterals in 1900.

The Tuolumne River is the District's primary source of water, originating at Mt. Lyell in Yosemite National Park. Water for irrigation and hydroelectric power production is kept at Don Pedro Reservoir about 50 miles east of Turlock in the Sierra Nevada foothills near the historic gold rush era town of La Grange.

Business focus:

Optimization of Reservoir Management

- Minimize Flood Threat
- Maximize Energy production
- Manage Water Accounting/Rights
- Manage Energy Dispatch
- Manage Renewable Energy
- Manage Environmental Releases to Tuolumne; flows, temperatures
- Manage Financial Risk Analysis
- Manage Irrigation Demands

Technical situation:

TID recognized a need for a central data hub to manage the massive amounts of data necessary to optimize the operations of Don Pedro Reservoir as well as downstream facilities without spilling, causing potential down stream flooding. The data hub must have the capability to automatically collect, validate, calculate, manage, and report real-time and archived data; integrate with existing applications like water resource management models; provide a decision support platform for water conservation and irrigation efficiency and monitor diverse inputs from environmental to energy production parameters.

Import data from:

- SCADA
- CDEC
- USGS
- NWS
- Financial systems

Export data to:

- Excel sheets
- Operations Models
- Hydrological Models

OVERVIEW OF WISKI

WISKI is a leading environmental data management software solution developed by KISTERS that has grown over the last 25 years into a mature solution that allows organizations to keep up with global advancements in technology and data management requirements. WISKI can be applied to many different applications as well as integrated into automated process management and control. WISKI can be used to manage all the tasks related to data management, from data importing through to final reporting. The WISKI solution uses advanced relational database management platforms such as ORACLE, or MSSQL to manage the data and is proven in both small and large installations around the world.

APPLICATION INTEGRATION

Resource management organizations often utilize a myriad of different data collection devices and presentation applications that are vital to their data management procedures, such as data loggers, Laboratory Information Management Systems (LIMS), SCADA, Geographical Information Systems (GIS), and spreadsheets. These all need to be taken into consideration and their data feeds integrated into a central data management system. The replacement of these applications by a single “mega” solution would be incredibly cost prohibitive and unnecessary if a data management solution that could integrate all the existing applications into a single solution was not commercially available. Without a comprehensive and integrated system, organizations may spend much of their time and energy simply transferring data from one application to another, greatly reducing efficiencies and potentially introducing unwanted error. Integration of the data collection and presentation applications inherently provides greater system efficiencies since data could be easily transferred from one application to another. Data quality resulting from validation routines performed in each application could also be preserved using this approach.

The availability of a COTS data management solution that has the ability to perform all the processes of data management, from collection to reporting, including the integration with other applications is limited. This type of system is much needed by irrigation districts and water resource managers, in general. Many data management systems offer only a single component of a comprehensive data management solution. This often leads to a combination of many different data management systems coupled together to try to solve the problem, often leading to errors and system instability issues.

Manufacturers of data loggers and other data collection equipment have greatly improved the software offerings that accompany their devices, as well as increased the amount of data they can store. Many of these device-specific data management solutions only have the ability to perform limited tasks concerning data records management. Organizations are routinely faced with collecting data with one type of data collection software/telemetry system, performing statistical calculations with a specific statistical software package, performing any data conversions or calculations within coupled spreadsheets, managing quality control within another management system, and then performing report generations through yet another software application. These loosely coupled systems always require reformatting of the data from one application to another, providing yet another potential opportunity for error. This type of data management system requires not only the need to keep track of the data processing workflow from one software application to another, but also to employ staff with the knowledge of how to operate the many different applications being used.

Typically, organizations either pay an outside software development firm to develop a customized system that incorporates the features and functions of the many different applications needed for data management procedures, or they are forced to continuously pass data files from one application to another to perform specific tasks. This type of data management system is an extremely inefficient use of both the data manager's time, as well as the organization's IT infrastructure. Many data management systems may be able to handle and process a small organization's data requirements, but they often have difficulty when dealing with the massive amount of data large organizations are mandated to manage.

Most organizations that are tasked with water resource management do not have a comprehensive and integrated data management system, yet require such a system to efficiently manage their data and the much valued data quality associated with it. The ability to manage all of an organization's needs, from the integration of data collection devices to reporting in a single software application would greatly increase efficiencies in time and reduce errors.

DATA COLLECTION

Data collection and environmental monitoring is becoming increasingly easier with technological advances in monitoring devices and reduction in data storage costs. This is accompanied by the request for more frequent data collection and the desire for real-time or near real-time systems. Not so long ago, simple monthly, weekly or daily mean readings of water level and flow was sufficient for the operation of an irrigation district and reporting to governing bodies. Nowadays, hourly and 15-minute readings are becoming the normal time resolution for data, with some moving towards collecting 5-minute data. The increase in data resolution is occurring for a number of reasons, including changing model input requirements, the desire to gain greater knowledge of monitored parameters and their trends, and the desire to gain a faster response to resource changes that require mitigating actions.

New models are emerging that allow organizations to predict the future of parameter states. With these models comes a greater need to collect data on, or near, a real-time basis so the models can produce a faster result of the future parameter conditions (Bigelow and David, 2003; Gerts and Linacre, 1998). These models are able to utilize high data resolutions (5 minute or less) to increase the probability of correctly predicting the future state of parameter conditions. Many models require an exact data raster (data at specific time intervals), with no missing values. Newer data loggers can support these high data resolutions and allow the models to operate directly on raw data coming in from the field. This eliminates the need for data to be interpolated to fit the strict data raster requirements of data models. However, models that run on raw data, without first adjusting for errors like spikes or sensor drift, can be problematic. This is especially so if alarm notifications and critical operation decisions are being based on this raw, unchecked data. Systems, like WISKI, has allowed Turlock Irrigation District to perform automated QA/QC on high resolution incoming data and pass it to models in near-real time, thus greatly reducing the possibility of costly errors.

DATA IMPORTING

As noted previously, the data logger industry is growing rapidly as technology improves to better serve the water resources community. The number of new data collection devices is growing each year, and so is the number of new data file formats produced by these devices. Even though some have the ability to configure certain aspects of their output data file format, nearly all data collection devices produce their own specific file format. With this flexibility in data file output formats comes increased complexities for data management systems as configurations for the same device may change from one organization to another. The nearly unlimited number of file formats and format variations illustrates the need for a data management solution to contain a fully configurable data file importing capability that can handle data from any collection device.

Irrigation districts that do not have a comprehensive data management system spend much of their time simply formatting data so that it can be imported into their existing system. Any organization would be able to increase their total data management efficiency by utilizing an automated data import process. Time saved by an automated import process could instead be spent on developing information from the data and making decisions based on this information. At the Turlock Irrigation District, savings in data processing time has exceeded 40% during normal non-flood control operating times

(38 labor hours per week savings) and upwards of 70% (73 labor hours per week savings) during flood control operation times since the introduction of the WISKI system.

Often irrigation districts are interconnected with other water delivery systems and thus are required to import data from different data sources other than their own into their data management solution. An important requirement of any data management solution is to be able to accommodate these various data sources in their system as they may need to validate or correct their data with it. With many data management organizations needing to perform data corrections or validation with data from other organizations, data management solutions must have the ability to contain multiple import time series locations to accommodate for the various data sources. With WISKI, the irrigation district is able to do so with ease.

DATA VALIDATION

Having the ability to record and track the quality of any data point is an essential criterion in deciding which data management system to use. Given the massive amounts of data these systems are now required to handle, a key feature a system should have is the automation of data validation procedures. Automated data validation is imperative to quality assurance and quality control (QA/QC) of field data. Data from the field may include a number of erroneous values for many different reasons, including low battery voltage, sensor fouling, sensor malfunction, improper installation, etc. Without proper data validation routines these erroneous values are often imported and could be incorporated into the final results that decision makers utilize. Along with erroneous data, gaps in the data may also be introduced by data loggers that have failed, been destroyed by flooding, removed by vandals, or simply had battery failure. These data gaps must either be filled or marked with a certain quality to ensure the correct processing of dependent calculations, such as stage to flow rating curves. The many sources of data errors need to be managed, controlled, and either corrected or validated to make sure that irrigation managers are not mislead by incorrect data when they are making important decisions. An efficient data management solution must therefore be able to automate data validation and correction routines to preserve good quality data and correctly qualify bad quality data.

A robust data QA/QC methodology is an essential part of any system to keep track of data quality throughout the entire data management process. A data management system must not only be able to track data quality throughout the validation process, but also be able to automate data quality changes based on specific validation routines, write remarks based on validation routines, keep track of who has edited the data, as well as keep track of remarks associated with each data value. The system should also contain a range of data qualities that may be customized by an organization to conform to their specific data management requirements. For instance, WISKI allows our irrigation district to establish up to 254 user-defined data quality levels. Although we do not utilize all of the levels, we have implemented a meaningful set of five quality levels in the system that includes good, estimated, suspect, unchecked, and missing.

Standardization of data quality values in an organization is necessary to preserve the same meaning throughout a data management system. Standardized data validation practices across all monitored parameters ensures consistent data quality through a data management solution. The District has been able to utilize several validation routines in WISKI in its day-to-day operations - threshold validation to change the data quality if the values are above or below specified set point, or compared to another time series, rate of change validation to change the data quality when values change at or beyond a specified rate over time, delta validation to change data quality when values change beyond a specified range, and distance validation to change the data quality when the time between two data points exceeds a specified time interval.

As the amount of data entering data management systems increases, validation processes must be automated to make them efficient and effective decision-support tools. Manual data validation processes take vast quantities of time that could be better used making critical operation decisions. The automation of data validation routines increases the efficiency of data management systems by reducing the amount of time hydrologists, engineers, and data managers spend on the QA/QC processing. A system with a robust and flexible QA/QC methodology that offers multiple automated validation routines enables our District to focus on making informed decisions with quality data.

DATA EDITING

Data collection devices are becoming more and more efficient, but nearly all data collection devices at some point log incorrect values for many different reasons. To be efficient, organizations must utilize data management systems that allow their managers to revise and edit incorrect data with ease. No two managers edit their data in the same exact way. Some prefer to edit data in tabular format, while others prefer a graphical format. Data management systems must be flexible enough to allow users to edit their data both graphically and within tables, as well as keep track of who, why and when the edits were made.

To determine who, why and when edits were made, an audit trail of edits becomes a necessary component of a data management system. Irrigation districts, as well as other public sector agencies require this component of data editing as they are often required to adhere to quality assurance oversight guidelines. The importance of an audit trail is paramount when there are multiple people working with the same data set. Organizations can then determine accountability and enforce internal guidelines if necessary.

When editing is being done both automatically by the system, and manually by different staff, having a way to visually inspect data qualities and comments for large ranges of data is imperative. WISKI includes an intuitive graphical control bar for reviewing data qualities and comments made by the system and users. By simply moving the mouse cursor over a particular part of the control bar, the entire audit trail of edits and comments can be visually inspected by the District staff. The unique color coding defined for each of the quality codes used in the system enables staff to quickly and efficiently understand the quality of the data, who has edited it, and any specific comments that were made along the way.

SCALABILITY

Irrigation districts have been collecting data on their operations for decades. With data collection devices becoming more and more proficient, organizations are moving towards collecting and storing higher resolution data sets. In parallel, more monitoring stations are currently being deployed at a fraction of the cost compared to a decade ago. Each of these stations can typically support the collection of 2-10 parameters, or more. With higher resolution data sets, an increasing number of monitoring stations, and multiple parameters being measured at each station, the scale of data collection is growing exponentially. For a typical irrigation district that collects five minute data, from ten parameters, at 50 different stations, it would result in collecting 17,520,000 data points every year! Some organizations may collect much more data, but a COTS data management system must be scalable to accommodate for both large and small organizations and the continuously growing amount of data these organizations collect.

Technological advances are not limited to the data logger industry. Hardware and hardware operating systems are also subject to continuous change and updates over time. Current COTS data management systems must take advantage of these innovations in order to meet the increasing demands of the environmental monitoring industry. Given the limited operating budgets of most irrigation districts, it is imperative that a COTS system take advantage of new technology, but also insulate the user from the cost of technology change.

WISKI's n-tier system architecture helps the District strike a perfect balance between monopolizing on advances in technology and meeting its environmental monitoring and operational goals. The District's WISKI system is composed of three scalable tiers – a thin desktop client, an application server, and a database server. The desktop client can be loaded directly on our workstations, or hosted via a terminal server or Citrix ©. The application server can be situated on either a virtual machine, or on its own hardware. Lastly, the database can even be split into separate components for high availability systems. With this type of system the District can safely deploy an unlimited number of stations, to collect an unlimited number of parameters and high resolution data sets without worrying about requiring a new data management system to meet these needs.

REPORTING

Reporting is typically the culmination and the ultimate goal of a data management system. They are essential tools that irrigation district managers use to help make their critical operational decisions. Since reports play such a pivotal role in the daily operation of an irrigation district, a high-quality reporting system is fundamental to any data management system. They offer summaries of many different types of information that may include daily, monthly, and yearly resource summaries, system efficiency gains and losses, and data management auditing checks to ensure proper data records management.

In some COTS data management systems the reporting process may be the most time consuming of all the data management processes. The ability to fast-track and automate the reporting process ultimately saves time and money. A system, like WISKI, with automated report generation is invaluable to an irrigation district. All the reports are streamlined in an automated process that allows them to be delivered through various media, such as email, FTP locations, and file sharing sites of our partner organizations. With the reporting capabilities of WISKI the District has experienced approximately a 60% increase in reporting efficiency (approximately 12 labor hours per week savings) during non-flood control operation times and approximately 130% increase in reporting efficiency (approximately 26 labor hours per week savings) during flood operating times compared to our previous system.

DATA EXPORT

The need to export data is often as important as the need for importing. The interconnected nature of the world's hydrologic cycle dictates that outputs from one process become critical inputs to another. The same applies to the operations of an irrigation district where the output from one district is often the input to another. Monitoring data therefore needs to be shared among organizations to facilitate the integrated management of water resources in a region.

Data sharing starts with the export of data from a data management system. This critical functionality must be present in any data management system. The system must also possess the ability to export data in multiple formats to enable the simple import into other applications. Flexible application programmable interfaces (API) provide the required ability to export data in an unlimited number of desired formats.

NECESSARY DATA MANAGEMENT TOOLS

A comprehensive water data management system is not only required to integrate with other applications, collect, import, validate, edit, report and export data, but also provide a suite of specialized tools to manage more complex tasks. Irrigation districts must be able to perform a number of complex calculations and analyses in order to conserve water and optimize their operational efficiency. The following subsections describe some of the data management tools that are necessary for the District.

Rating Curve Conversions

Many environmental parameters must be monitored, however, for some there is no direct method of measurement. In this case, these parameters have to be determined through relationships to another measureable parameter. At the District, rating curves are routinely used to represent the relationship between stage and flow. The relationship of these vital parameters rarely stays constant through time as changes in channel geometry can affect the calculated flows. The relationship between stage and reservoir volume, or stage and surface area also changes due to erosion of the reservoir's banks, sedimentation, or vegetation growth and must be calculated using a rating curve. With the nearly continuous relational change between some parameters, a data management system must not only be able to handle rating curves, but also be able to manage an unlimited number of rating curve versions to keep track of the changing relationship between the parameters.

Regression Analysis

The relationship between parameters rarely follows a linear pattern, therefore the rating curve manager portion of a data management system must allow for regression analyses to be conducted in multiple sections on observed measurements. Regression analyses in multiple sections allow a system to characterize sharp differences in parameter relations that a single regression analysis may not be able to. Multiple regression sections supply a good fit where sharp changes in channel geometry occur. Relational parameters may follow a specific pattern through one section of relationships, but may follow a completely different relationship pattern in other sections. For this reason, data management systems must be able to perform single and multiple regression analyses to characterize the changing relationship of two parameters.

Statistical data calculations

The natural environment is extremely variable. Statistics are one way to describe the variability of a monitored parameter over time. Data management systems must be able to perform statistical analyses on data sets in order to determine if the current state of a parameter is beyond a certain deviation of its mean and warrants alarming and/or action. Statistical calculations are needed at an irrigation district for a vast number of reasons, including mean, minimum, and maximum daily production and efficiency statistics that can be used to optimize system resources. Beyond the standard statistical calculations mentioned above, data management systems must also include sufficient flexibility to configure unique statistical calculations, such as the 30-year 95th percentile of all January values. The District requires these statistical analyses to be automated as new data enters the system. WISKI's automation of statistical calculations has dramatically decreased the time the District's managers spend calculating these values.

System efficiency calculations

Irrigation districts constantly strive to achieve a maximum operating efficiency. However, naturally occurring cracks in drainage canals and pipe networks produce unexpected gains or losses in delivered volumes. Organizations must be able to determine the gains and losses within the system that were not accounted for by the known system inputs and outputs. Unexpected gains and losses may result in many undesired results, including loss of revenue as the system loses resources, or system overload due to unexpected gains. The ability for a data management system to store an unlimited number of data points for an unlimited number of stations would allow organizations to more fully monitor their managed resources. With the increased ability to monitor resources, such as the total flow of a channel throughout a channel network, organizations are able to determine the sections of a system where unexpected inputs or outputs are located by calculating the difference between the upstream and downstream channel flow. This calculation is described as follows:

$$\Delta flow = Dflow - Uflow$$

Where:
$\Delta flow$ is the change in flow
$Dflow$ is the downstream flow
$Uflow$ is the upstream flow

Any unknown inputs and outputs to a channel system may be detected with this simple water balance equation. This simple water balance equation may be modified to account for further inputs and outputs to a channel system as shown below.

$$\Delta flow = Dflow - Uflow - \Sigma Inputs + \Sigma Outputs$$

Where:
$\Delta flow$ is the change in flow
$Dflow$ is the downstream flow
$Uflow$ is the upstream flow
$\Sigma Inputs$ is the sum of inputs to the system
$\Sigma Outputs$ is the sum of outputs to the system

WISKI provides the District with a flexible and robust framework in which simple or complex system efficiency calculations can be made. These calculations can be performed on an automated basis and the results provided to managers in near real-time. This capability has enabled the District to maintain a tight control over its entire operations and achieve significant efficiencies in operation.

THE SOLUTION

KISTERS has developed a COTS data management system that is able to provide irrigation districts with all the necessary components to successfully and efficiently operate their networks. The KISTERS' WISKI solution is a scalable, flexible and comprehensive data management solution that allows for automation of every step in the data management processes. From data imports, validation, processing, statistical and system efficiency calculations to reporting an organization's standard reports through various media such as email, FTP locations, shared folder locations, etc., WISKI has been the ideal choice for the District.

WISKI's data structure is based on a hierarchical layout of sites, stations, parameters, and time series. An unlimited number of sites may exist within the system, containing an unlimited number of stations, at which an unlimited number of parameters are measured, and an unlimited number of time series stored. The time series provides a place holder for all data values being collected. WISKI also allows for many different versions of time series to be stored. Original data, validated data and production data can exist simultaneously in separate time series in conjunction with others containing statistical calculations, water balance calculations, key performance indicators (KPI's), and system efficiency calculations. Throughout the entire workflow the quality value for each data point is preserved and an audit trail kept for future reference.

CONCLUSION

There are many necessary components to a data management system that irrigation districts require to provide them with a comprehensive solution. The requirement for a scalable solution that allows for the automation of every step in the data management workflow is critical. The system must also include data import, data validation, data processing, statistical and system efficiency calculations, and reporting capabilities to fulfill the necessary requirements of a district. Lastly, the inclusion of specialized tools necessary for managing water data is a fundamental requirement for any COTS data management system.

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REAL-TIME OPTIMIZATION FOR SMART AUTOMATION OF SURFACE IRRIGATION

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ABSTRACT

A system for the real-time optimization of furrow irrigation is described. The system estimates the soil infiltration characteristics in real-time and utilizes the data to control the same irrigation event to give optimum performance for the current soil conditions. The main features of the system are: the use of a model infiltration curve and a scaling process to describe the current soil infiltration characteristic; measurement of the inflow rate to the furrows; measurement of the water advance at a point approximately midway down the furrow; and a microcomputer running a hydraulic simulation program based on the full hydrodynamic model to predict the optimum time to cut-off.

The system was trialed on a furrow-irrigated commercial cotton property utilizing pipes through the bank (PTBs) to supply groups of furrows. The initial observations from these trials are presented in this paper and demonstrate that improvements in water use efficiency are potentially achievable through the use of the system.

Extensions to the system to improve its performance and to make it applicable to bay irrigation are described.

INTRODUCTION

Surface (bay and furrow) irrigation is one of the most commonly used methods for irrigating crops and pastures in Australia and around the world due to the low cost and low energy requirements. While well designed and managed surface irrigation systems may have application efficiencies of up to 95%, many commercial systems have been found to be operating with significantly lower and highly variable efficiencies. Previous research in Australia in the sugar and cotton industries (Raine and Bakker, 1996, Smith *et al.,* 2005) found application efficiencies for individual furrow irrigations ranging from 10 to 90%. Fewer data were available for bay irrigation of pasture and fodder crops but a similar performance is indicated (Smith *et al.*, 2009).

The efficiency of surface irrigation is influenced by the field design and the infiltration characteristics of the soil, but is primarily a function of the irrigation management.

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However, the complexity of the interactions makes it difficult for irrigators to identify optimal management practices. The infiltration characteristic of the soil is a dominant factor in determining the hydraulic behaviour of surface irrigation and both spatial and temporal variations in the infiltration characteristic are a major physical constraint to achieving high irrigation application efficiencies (Shafique and Skogerboe, 1983). The spatial and temporal variation commonly found in infiltration characteristics (Raine *et al*., 1997) within a field also limit the usefulness of generalised design and management guidelines for surface irrigation.

Real-time optimization of individual irrigations can help to overcome the effect of these spatial and temporal variations and provide a significant improvement in irrigation performance. Coupling this real-time optimisation with automation gives the 'smart automation' where the time to cut-off (and possibly flow rate) are varied automatically in response to the behavior of an irrigation to give the maximum performance for that irrigation. A number of simulation studies (e.g. Raine *et al.,* 1997, Smith *et al.,* 2005, Khatri and Smith, 2007, Gillies *et al*., 2010) have quantified the potential improvement in irrigation performance achievable through real-time optimization and control. When the management parameters were optimized to simulate perfect real-time control of individual irrigations, average application efficiencies in excess of 90% resulted along with storage efficiencies also greater than 90%.

Previous systems developed for real-time control (e.g. Azevedo *et al.,* 1992, Camacho *et al*., 1997) have not shown themselves to be commercially feasible. The major limitations are that they were excessively complex, too data intensive and too expensive. A viable system needs:

1. A simple control strategy,
2. Minimum sensing,
3. Robust and reliable simulation, and
4. Optimization to a simple user defined objective.

Extracting the best information on the soil infiltration characteristic from a minimum quantity of field data is central to the practical real-time control of surface irrigation (Oyonarte *et al*., 2002). The conundrum is that the quality of estimates is directly related to the quantity of data used. Current methods estimating infiltration tend to focus on advance data but infiltration (and Manning *n*) estimates can be improved greatly by inclusion of depth, recession and/or runoff data (Gillies and Smith 2005, Walker, 2005, Gillies *et al*., 2010). However, the cost and installation of the necessary sensors limits the use of these data in control systems. Further, many of these data occur too late in the irrigation to be of any use for control.

Khatri and Smith (2006) provided the basis for simple real-time optimization using a model infiltration curve for the field in question and an event-specific infiltration characteristic determined from a single advance measurement and a process of scaling. The method is based on the premise that for any field the shape of the infiltration characteristic remains the same but the magnitude varies spatially and temporally. A furrow is selected as the model furrow and extensive advance and run-off data are used to calculate the parameters in the Kostiakov-Lewis infiltration equation:

$$I = k\tau^a + f_o\tau \tag{1}$$

where I is the cumulative infiltration (m^3/m),
a, k, and f_o are the fitted parameters, and
τ is the infiltration time (min).

The cumulative infiltration curve calculated from these parameters is the 'model infiltration curve'. Subsequently the model infiltration parameters can be used to estimate (by scaling) the cumulative infiltration curves for other furrows, and other irrigation events, using only one advance point for each of the remaining furrows or each subsequent irrigation event.

A scaling factor (F) is formulated for each furrow or event from a re-arrangement of the volume balance model as used by Elliot and Walker (1982) and McClymont and Smith (1996):

$$F = \frac{Q_o t - \sigma_y A_o x}{\sigma_z k t^a x + \dfrac{f_o t x}{1+r}} \tag{2}$$

where Q_o is the inflow rate for the corresponding furrow (m^3/min),
A_o is the cross-sectional area of the flow at U/S end of furrow (m^2) (determined by any appropriate method),
a, k, f_o are the infiltration parameters of the model furrow,
σ_y is a surface shape factor taken to be a constant (0.77),
σ_z is the sub-surface shape factor for the model furrow,
r is the exponent from power curve advance function $x = p(t)^r$ for the model curve,
t (min) is the time for the advance to reach the distance x (m) for the irrigation event being controlled.

This scaling factor (F) is then applied in conjunction with the Kostiakov–Lewis infiltration model to scale the infiltration curve for the irrigation event being controlled:

$$I_s = F(k\tau^a + f_o\tau) \tag{3}$$

where I_s is the scaled infiltration (m^3/m), and
a, k, f_o are the infiltration parameters of the model furrow.

The major disadvantage with this approach is the use of the volume balance equation and the various empirical factors σ_y, σ_z, and r the values of which must be estimated. All have a significant effect on the outcome of the scaling.

Subsequent to this work a new surface irrigation simulation model (Gillies *et al*., 2010) was developed by the authors and which has provided the basis for the software required for real-time simulation. The model SISCO (*Surface Irrigation Simulation Calibration and Optimization*) is an application of the full hydrodynamic equations for spatially varied flow as described by McClymont (2007). In calibration mode, SISCO estimates the infiltration parameters and roughness parameter (Manning *n*) from the inflow hydrograph and any combination of the advance data, runoff hydrograph, water depth measurements and recession times. SISCO can accommodate variable inflow and variable slope in both calibration and simulation modes. The calibration screen of SISCO is shown in Figure 1, where the three infiltration parameters and Manning *n* are determined for an irrigation bay from depth measurements at 7 locations down the bay.

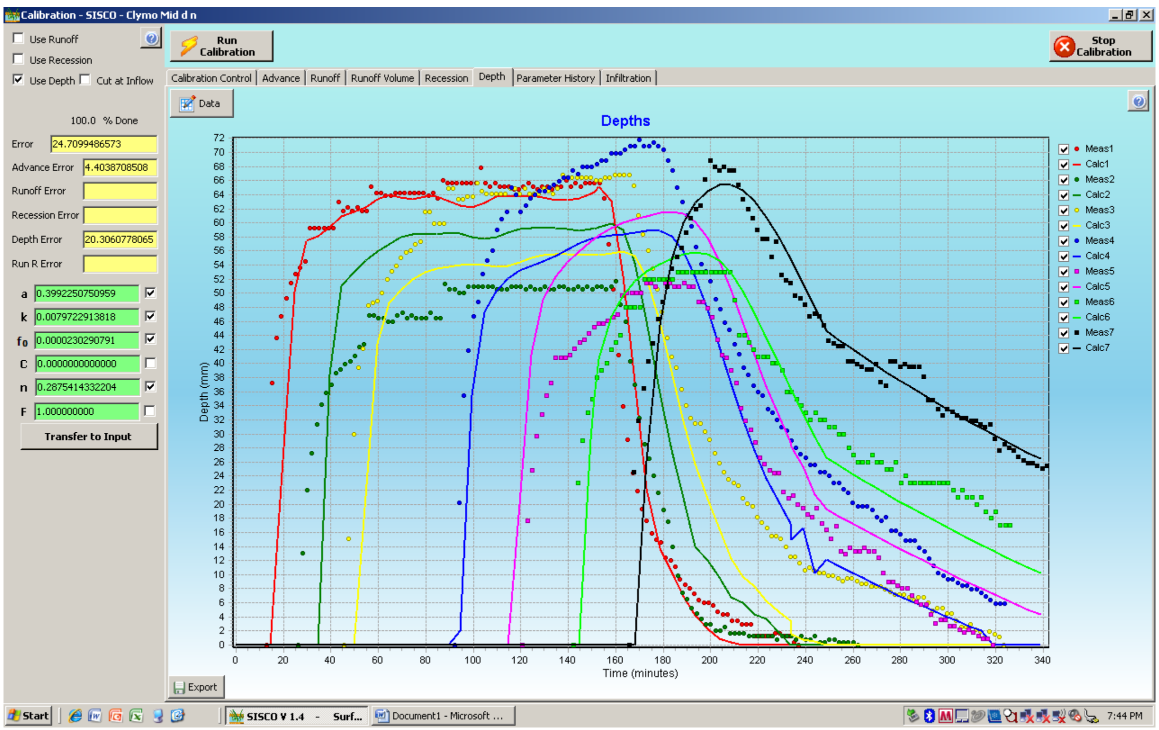


Figure 1. Calibration Screen of SISCO Showing Measured and Calculated Depths at Various Locations down an Irrigation Bay

In this paper, the results of preliminary trials of the real-time optimization are presented and improvements are proposed to the approach developed by Khatri and Smith (2006). It is extended to include bay as well as furrow irrigation, to use SISCO to perform the scaling as well as the simulation and optimization, to accommodate the spatial variability of infiltration between furrows, and to include a self learning capability that progressively refines the model curve.

THE BASIC REAL-TIME OPTIMIZATION SYSTEM

The system follows directly from that proposed by Khatri and Smith (2006) and uses their concept of the model infiltration curve. In its simplest form it uses a predetermined inflow rate and maximizes performance by varying the time to cut-off. This is justifiable because experience has shown that if the flow rate is selected appropriately to begin with then varying it gives little improvement in performance, although if the physical control hardware allows inflow to be varied the system can accommodate it.

Field Characterization

Before the system is implemented in any bay or set of furrows, the initial model infiltration curve must be established. The best estimate comes from the usual process of inverse solution by SISCO in calibration mode from advance and other measurements taken during an irrigation. However, in the absence of such measurements it can be estimated from soil texture or experience. The inflow rate to be used is also set at this time from trial simulations performed using the model infiltration curve in SISCO.

The physical characteristics of the furrows or bay such as length, slope and cross section shape are also required.

Optimization and Control

The optimization and selection of the preferred time to cut-off during each irrigation event, in each set of furrows, involves the following steps.

1. *Soil moisture deficit*. This can be determined from soil moisture measurements or from a soil moisture balance based on estimates of crop water use since the last irrigation.

2. *Measurement of inflow*. The system can use either a constant inflow or a continuous inflow hydrograph. To avoid the expense of flow metering, inflow is inferred from water depth or pressure depending on the inflow system. For example, for a set of furrows supplied by flexible gated fluming, the inflow to each furrow can be calculated from the pressure in the fluming using the gated pipe program of Smith (1990). This information is implemented in the system as a look-up table of pressure versus flow specifically prepared for that set of furrows. Similarly, for other inlet configurations the look-up table would be developed from the head-discharge relationship for the particular structure.

3. *Advance*. A single advance measurement (time for the known distance) is taken at a point approximately mid-way down the field. This measurement triggers the commencement of the simulation modelling and optimization.

4. *Infiltration scaling*. The model uses the measured inflow and the advance time to the known point to calculate the scaling factor (equation 2) and hence the infiltration

characteristic (equation 3) for that particular irrigation. This is then used in the optimization.

5. *Optimization*. The optimization employs a derivative of the SISCO model which selects the time to cut-off that gives the best performance according to a user defined objective function. For example, one simple objective that satisfies the requirement of many growers is to maximize the application efficiency E_a while ensuring that at least 90% of the soil moisture deficit is satisfied and a minimum depth is applied at the downstream end of the field (ensures that the advance reaches the end of the field). However more complex objectives specifying uniformity, deep drainage and runoff targets can be used but might serve to reduce the robustness of the system.

6. *Control*. Finally, the inflow is cut-off at the designated time and the process is repeated for subsequent sets.

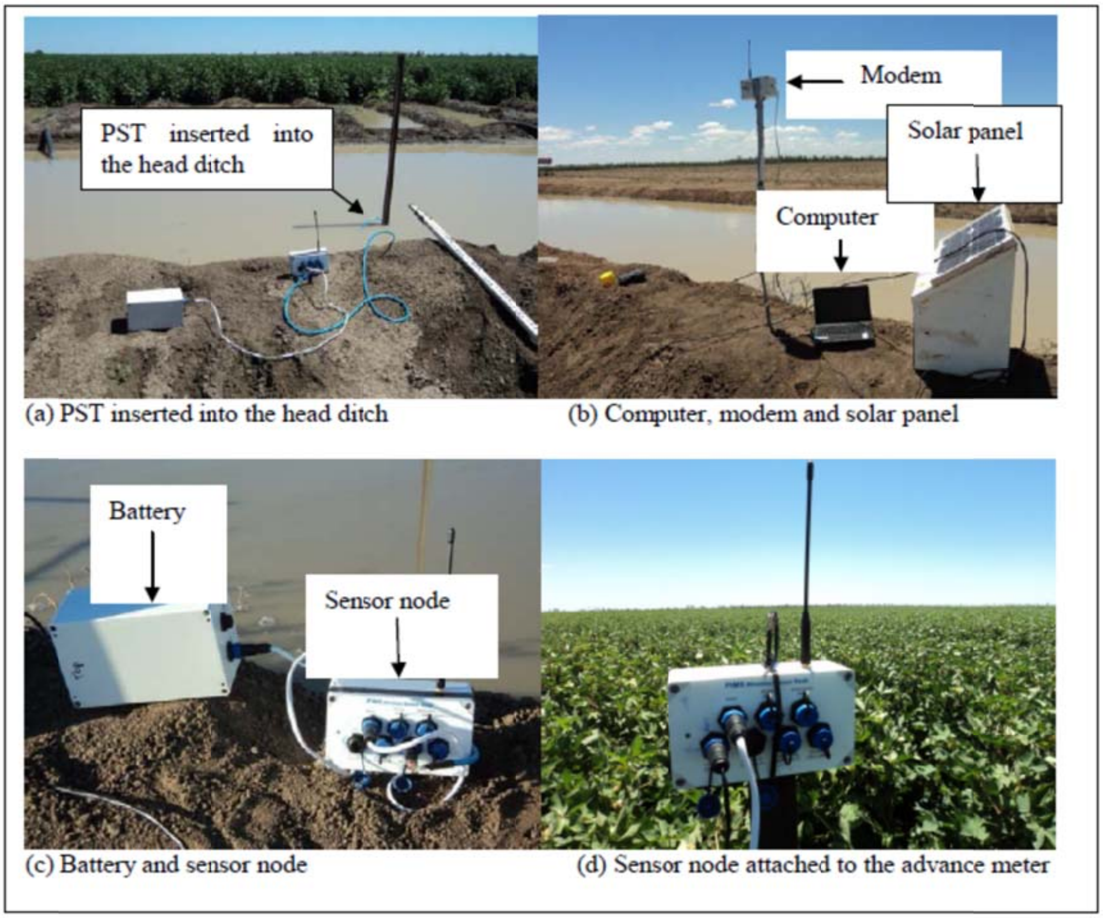
PRELIMINARY TRIALS

Trials were undertaken on a commercial furrow-irrigated cotton property at St George in south-western Queensland, Australia. Four irrigations in the summer season 2010/11 were monitored in a section of the field that used pipes-through-the-bank (PTB) to supply groups of 11 furrows (Figure 2). The furrows were 970 m long and spaced at 1 m apart.

The flow rate was inferred using head measurements in the supply channel and a calibration equation for the PTB. The model curve used in the software for each irrigation was obtained from the actual infiltration curve from the immediately preceding irrigation. The advance sensor (with the associated components) was placed 500 m from the inlet. Communication between the various components was via radio telemetry. The inflow was terminated manually at the predicted time to cut off.

A significant outcome from the trials was that the real-time optimization model (sensing, infiltration scaling, simulation and optimization) performed robustly and reliably without user intervention.

Sample results from the trials are provided in Table 1. They show that with the exception of Trial 4, the irrigation times predicted were shorter than those used by the farmer in irrigating the remainder of the field. This translated to reduced runoff and deep percolation and higher application efficiencies as a direct result of the real-time optimization. It is also apparent from this table that the farmer was utilizing the knowledge gained from preceding irrigations to modify his future management practices. He progressively reduced both the inflow rate and irrigation times throughout the season. It is for this reason that the final irrigation of the season (Trial 4) had a shorter cut-off time than that predicted by the real-time optimization. In this case the farmer controlled irrigation failed to reach the end of the field.



(a) PST inserted into the head ditch
(b) Computer, modem and solar panel
(c) Battery and sensor node
(d) Sensor node attached to the advance meter

Figure 2. Equipment used in the Preliminary Trials

Table 1. Trial Results

	Irrigation number			
	1	2	3	4
Inflow (l/s)	6	5	3.8	3.3
Soil moisture deficit (mm)	80	80	82	90
Predicted performance[2]				
Time to cut-off[1] (min)	280 (565)	392 (489)	408 (484)	568 (480)
Application Efficiency E_a (%)	72	66	83	73
Requirement Efficiency E_s (%)	93	100	98	94
Potential performance[3]				
Application Efficiency E_a (%)	99	72	91	100

[1] Farmer's time to cut-off shown in brackets.
[2] Predicted by the real-time optimization.
[3] Based on optimization using the actual infiltration curve.

Despite the evident gains from using the real-time optimization, none of the controlled irrigations reached their full potential, as shown by the potential efficiencies listed in Table 1. One contributor to this was the failure of the scaling process to provide an accurate estimate of the actual infiltration characteristic. The two causes of this were identified as the use of the volume balance model for the scaling and a less permeable soil in the lower half of the field. Typically the scaled infiltration was higher than the actual average infiltration characteristic and hence the times to cut-off predicted were greater than actually required.

THE NEW REAL-TIME OPTIMIZATION SYSTEM

Extension to Bay Irrigation

Bay irrigation of pasture or fodder crops differs from furrow irrigation in some ways that influence the real-time optimization significantly. In Australia bays are typically very much shorter than irrigated furrows (200 to 600 m c.f. 600 to 1500 m). The surface roughness is also very much greater (Manning *n* values typically 0.2 to 0.4 c.f. 0.04 for bare furrows) and varies with time (pasture condition). This means a much greater volume of water is temporarily stored on the surface of the bay in the irrigation flow and the hence inflow can be cut-off earlier in the irrigation, in some cases before the advance has reached the half way distance down the bay. These factors combine to make the real-time optimization more difficult in bay irrigation.

For furrow systems a single advance measurement approximately mid-way down the field is sufficient to perform the infiltration scaling (assuming the Manning *n* is known or can be estimated from the furrow characteristics), and allows sufficient time to make the control decision on optimum time to cut-off. For bay irrigation, the need to estimate the Manning *n* as well as the scaling factor requires either two advance points or multiple depth measurements at a single point. Because of the shorter times to cut-off for bay irrigation, the measurements need to take place within the first third of the field. Even so there is less time to undertake the optimization and make the control decisions. A depth sensor that continuously records flow depth is best used in lieu of the advance sensor (the depth data can be used later in the self learning feature).

Scaling the Model Infiltration Curve with SISCO

The preliminary trials showed that the infiltration scaling using the volume balance model was too dependent on the three shape parameters σ_y, σ_z, and r. Subsequently the optimization model (based on the SISCO model) which does not use these parameters has been modified to undertake this task. It uses the measured inflow and the model infiltration curve in a series of simulations and simply varies the scaling factor F (and Manning n) until the simulated advance (or depths) match the measured values.

Self Learning

Conducting an evaluation of an irrigation for each bay or set of furrows to obtain the model curve for each is expensive, time consuming and requires specialized equipment. An alternative is to introduce a self learning capability into the system whereby an initial estimate of the model curve is improved with each subsequent irrigation. For this self learning, the flow and depth measurements (taken early in the irrigation for use in the control loop) are continued throughout the entire irrigation. These data are then used to revise the model infiltration curve and check the adequacy of the inflow rate used in the irrigation, as follows.

Firstly, in calibration mode the modelling software can use the inflow and depth data to calculate the actual infiltration characteristic for the irrigation just completed. This can then be averaged with the characteristics from any previous irrigations to give the updated model curve. In this way the model curve is refined to ensure that its shape is truly representative of the soils in the particular field.

Second, the model can use the actual infiltration characteristic in optimization mode to determine the inflow that would give the best possible irrigation performance. If the calculated inflow rate is markedly different from that used in the irrigation, the user can be given the option to alter the flow rate for the next irrigation.

Accommodating Spatial Variability in Furrow Irrigation

For furrow irrigation all of the above measurement, simulation and optimization take place in a single furrow. However it is well known that there is considerable variation in the infiltration characteristics between furrows and hence in the irrigation performance between furrows in the same field or set (e.g. Gillies *et al*., 2008 & 2011). This is illustrated in Figure 3 which shows the variation in completion times for a set of 80 furrows on a cotton farm in central Queensland. The irrigation illustrated in Figure 3 was relatively well managed with an application efficiency of 78%. Runoff was 8.9% but varied from 0 to 24% for the individual furrows. Deep drainage averaged 14 mm (range 0 to 27 mm).

Given this knowledge of the statistical variation between furrows (from the variation of completion times across the set), SISCO can perform a whole set optimization and determine the flow rate and time to cut-off that gives best performance for the set as a whole. For example, for the field in Fig 3, optimization increased the application efficiency to 84%, reducing deep drainage to 6.5 mm but increasing runoff to 10%.

The consequence for the real-time optimization system is that the time to cut-off for best performance in the control furrow may not correspond to that which gives best performance for the entire set (Gillies *et al*., 2008). However if the statistical variation between furrows is known, SISCO can provide the relationship between the control furrow and the whole set. This can then be used to adjust the scaling factor to allow the control furrow to better represent the set.

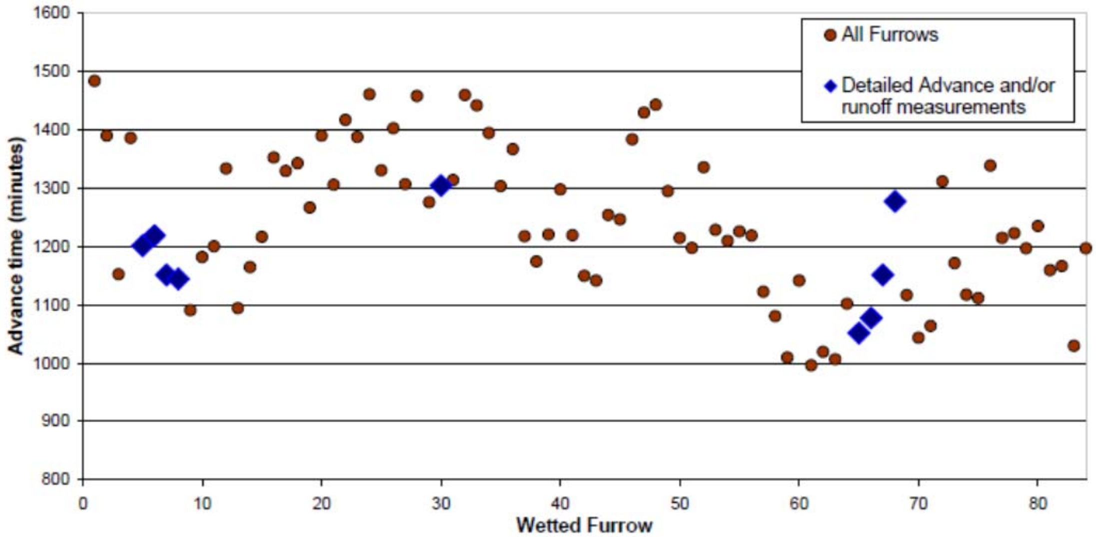


Figure 3. Variation in completion times for a furrow irrigated field of 80 furrows (from Gillies *et al*., 2008)

Figure 4. Automated Bay Outlet and Water Depth Sensor for the FarmConnect® System (Rubicon Water publicity brochure)

Automation and control

While the real-time optimization can be operated as a manual system the greatest benefits occur when it is integrated with automation. The desired time to cut-off is transmitted to the control hardware. The development of this hardware is outside the scope of the current project. The intention is to use a commercially available system such as the Rubicon Water FarmConnect® system (Figure 4). Work on extending the system as described above has commenced and is due to be trialled on two properties in the coming 2011/12 irrigation season.

CONCLUSIONS

A system for the real-time optimization of furrow irrigation has been developed and tested. It has been shown to give improved irrigation performance although it fell short of delivering the maximum performance. Improvements to the system have been described along with its extension to bay irrigation.

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SUPERVISORY CONTROL AND DATA ACQUISITION MEETS PUBLIC POLICY — A GLENN-COLUSA IRRIGATION DISTRICT CASE STUDY

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Thaddeus Bettner, PE [2]

ABSTRACT

Looking into the future, water agency managers, consultants, board members and other decision makers will need to assess and consider using today's available technology to make more informed decisions to balance competing needs for water, to demonstrate improved water management, and to implement and manage water conservation programs. The initial investment and "growing pains" of using technology to install or update a system can streamline operations and serve multiple functions to improve efficiency and data acquisition. With this foundation, Glenn-Colusa Irrigation District (GCID) elected to proceed with installing and utilizing a Supervisory Control and Data Acquisition (SCADA) system to improve operations and assist in addressing the myriad challenges associated with operating a large irrigation district in California.

Internal to GCID, the SCADA system is part of a long-term strategic plan to enable improvements to control the distribution and delivery of irrigation water through GCID's extensive canal network. One of the most important components of GCID's SCADA system is the communication system, which is a high-speed endlessly expandable communication network capable of adding an unlimited amount of SCADA sites.

External to GCID, California's policy makers continue to enact new legislation requiring water agencies to prove that they are accurately measuring water, to demonstrate that water is being efficiently managed and beneficially used, and to establish linkages between surface water and groundwater. GCID is in the process of expanding its SCADA system to meet these new public objectives.

INTRODUCTION

Glenn-Colusa Irrigation District's water rights begin on the Sacramento River with an 1883 filing posted on a tree by Will S. Green, surveyor, newspaperman, public official, and pioneer irrigator. His first claim was for 500,000 miner's inches under 4 inches of pressure and was one of the earliest and largest water rights on the Sacramento River.

GCID was organized in 1920, after several private companies failed financially, and a group of landowners reorganized and refinanced the irrigation district, retaining claim to Green's historic water right. The disastrous rice crop failure of 1920–21 nearly destroyed the District at its inception and the Great Depression took a further toll, making it

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necessary for the district to refinance in the 1930s. Additionally, the United States purchased lands within GCID during this period that would later become three federal wildlife refuges totaling over 21,000 acres.

Today, after surviving many challenges, GCID is the largest irrigation district in the Sacramento Valley. Located approximately 80 miles north of Sacramento, California, the District boundaries encompass approximately 175,000 acres, with 141,000 planted acres and over 21,000 acres within three federal wildlife refuges that provide critical wildlife habitat. There are an additional 5,000 acres of private habitat land, and water supplied by GCID to thousands of acres of rice land provides valuable habitat for migrating waterfowl during the winter months.

GCID's main pump station, its only diversion from the Sacramento River, is located near Hamilton City. Prior to water entering the pump station, river water passes through an 1,100-foot long fish screen, built in the late 1990s (Figure 1). Water is then lifted an average of 4 feet before entering the conveyance system (Figure 2). The District's 65-mile long main canal conveys water into a complex system of nearly 1,000 miles of canals, laterals and drains, much of it constructed in the early 1900s.

Figure 1. SCADA allows GCID to monitor the activities of its 1,100-foot long fish screen. The pump station is located directly behind the fish screens.

Figure 2. GCID's main pump station, located on the Sacramento River, has the capability of pumping 3,000 cubic feet per second (cfs). SCADA allows canal operators to make pump changes remotely, monitor water elevations, and measure the water quality entering the District's main canal.

WATER SUPPLY

From the time of its first diversions until 1964, GCID relied upon historic water rights and adequate water supply from the Sacramento River system. This system receives rainfall and snowmelt from a 27,246 square mile watershed with average runoff of 22,389,000 acre-feet, providing nearly one-third of the state's total natural runoff. In 1964, after nearly a decade of negotiations with the United States, GCID along with other Sacramento River water rights diverters entered into "Settlement Water Contracts" with the Bureau of Reclamation (Bureau). These Settlement Contracts were necessary at that time to allow the Bureau to construct, operate, and divert water for the newly constructed Central Valley Project (CVP). The contract provided GCID with water supply for the months of April through October consisting of 720,000 acre-feet of base supply, and 105,000 acre-feet of CVP water that is purchased during the months of July and August. During a designated critical year when natural inflow to Shasta Reservoir is less than 3.2 million acre-feet, GCID's total supply is reduced by 25%, to a total of 618,750 acre-feet.

Additionally, the District has rights under a State Water Resources Control Board (SWRCB) permit for "winter water" from November 1 through March 31 at a 1,200 cubic feet per second (cfs) diversion rate. This water supply is used for rice straw decomposition and waterfowl habitat. The permit provides 150,000 acre-feet for rice straw decomposition and 32,900 acre-feet for crop consumption. Groundwater can also be used to supplement GCID's supplies, with 5,000 acre-feet available from District wells, and approximately 45,000 acre-feet from privately owned wells.

IMPROVEMENTS TO FLOW MEASUREMENT AND DATA MANAGEMENT PROCESSES

GCID continues to improve its flow measurement and related data management processes. Existing processes have evolved in a manner that adequately supported water operation and administration, but do not necessarily support more recent efforts to refine water management policy and practice in response to existing and anticipated challenges to water supply reliability.

GCID has prepared an annual *Water Measurement Report* (Annual Report) since 1964 that serves as a record of annual water diversions, operations, and uses. It consists primarily of a series of tables that summarize water diversions, deliveries, drain flows and drain water recapture on a monthly and annual basis, and contains a large amount of information and enables tracking of trends in certain operating parameters. The Annual Report also documents the water rates, rainfall, cropping patterns, and policies in effect each year.

Until 2009, GCID maintained a spreadsheet-based data management system that had been designed to produce operational reports and summary tables contained in the Annual Report. The spreadsheet system employed macro programs to enable semi-automated data entry, but the data was stored in a highly compartmentalized manner, making data access, analysis and reporting difficult. The system performed adequately for nearly 20 years for routine operations but was cumbersome for investigative analyses and ad hoc reporting, and it was not structured to receive and manage data from GCID's expanding SCADA network.

In early 2009, GCID migrated its spreadsheet data system to a Microsoft Access relational data base. This involved extracting data stored in hundreds of spreadsheets and assembling the data in one large Access data base. All of the historical data was salvaged. The new data base retained as much of the terminology as possible from the old system, including measurement site reference numbers and names. Like the old one, the new system includes data input screens designed to facilitate hand entry of operator reports submitted orally by radio and in writing.

One major objective of the conversion to a data base environment was to accommodate the growing volume of operational data that was expected to come from GCID's SCADA system. Over time, it is expected that GCID's reliance on SCADA information will increase and manual operator reporting will decrease. This trend is typical of many irrigation districts that are implementing SCADA systems for remote monitoring and control of water distribution systems.

It is anticipated that the capacity limits of Access will be exceeded and the data base system will have to be migrated to a higher capacity platform, such as SQL server or Oracle. This migration will be relatively straightforward now that data is stored in data base tables. Eventually, GCID intends to house or access all of the data needed for water balance analysis in an integrated Water Information System (WIS). A major consideration in the design of the WIS is to enable routine updates of GCID's water balance model.

SUPERVISORY CONTROL SYSTEM OVERVIEW

GCID's delivery system is comprised of the main canal, which is the major conveyance feature that extends 65-miles in length from the north to the south end of the District, 24 check structures that maintain upstream water level elevation, approximately 500 miles of laterals that convey water from the main canal, and approximately 2,500 field turnouts. The District's conveyance system includes 19 recapture pump sites and 17 gravity recapture sites that recycle over 200,000 acre-feet annually.

For control purposes, GCID's SCADA Project was designed to maintain constant upstream water elevations. As all water delivered to GCID customers either comes directly from the main canal or laterals from the main canal, it was vital that constant water elevations were maintained which would ensure constant flow deliveries from the main canal. Historically, water operators would make manual gate changes in the main canal check structures (Figure 3) in attempt to match water orders and flow requirements; however, in most instances, it was difficult to match these changes perfectly. The result would be that the water levels in the main canal would fluctuate and result in fluctuating flows to the District's customers.

Figure 3. Typical check structure along the main canal; SCADA allows the radial gates to move automatically, maintaining a selected or targeted upstream water elevation.

In order to meet California's new legislative requirements and to demonstrate that water is being efficiently managed and beneficially used, improving the water deliveries to customers was a critical first step. Due to the hydraulic complexity of the main canal, GCID consulted with Irrigation Training and Research Center (ITRC) personnel at California Polytechnic State University, San Luis Obispo, who developed the technical specifications, conceptual designs, and control strategies. The design phase began in July of 2007, and was followed by a radio survey conducted in June of 2008. Actual construction of the project commenced in the fall of 2008 and was completed in December 2010. The 2011 irrigation season was the first full season of operations with the SCADA system in place.

The SCADA system has enhanced water management by maintaining constant water levels in the main canal. This allowed water operators to conserve water at the operational spill points, and results in water users conserving water due to the flows into their fields remaining consistent. The project has improved system efficiency by removing the wave actions that historically created difficulties in determining whether river diversions needed to be increased or decreased.

GCID's conveyance system consists of drains supplementing laterals and, in other cases, laterals supplementing other laterals. In order to fully utilize the District's system, it is important to have as much real time information available as possible. Managing the main canal is only the first phase of a long-term strategic plan to enable GCID to monitor all critical points within the system to minimize drain outflows, and beneficially use the water rights of the District.

Technical Information

GCID's SCADA network consists of a dedicated system running ClearSCADA software (2009 version) on dual (redundant) servers in a Windows Server 2003 environment. The main SCADA workstation is a separate desktop computer connected to a 33-inch widescreen flat panel monitor that uses ClearSCADA View X. The SCADA system allows water operations staff to remotely operate the main canal system from work stations located at GCID's main office, or from laptops in the field using an internet connection. (Figure 4) depicts SCADA sites currently being monitored.

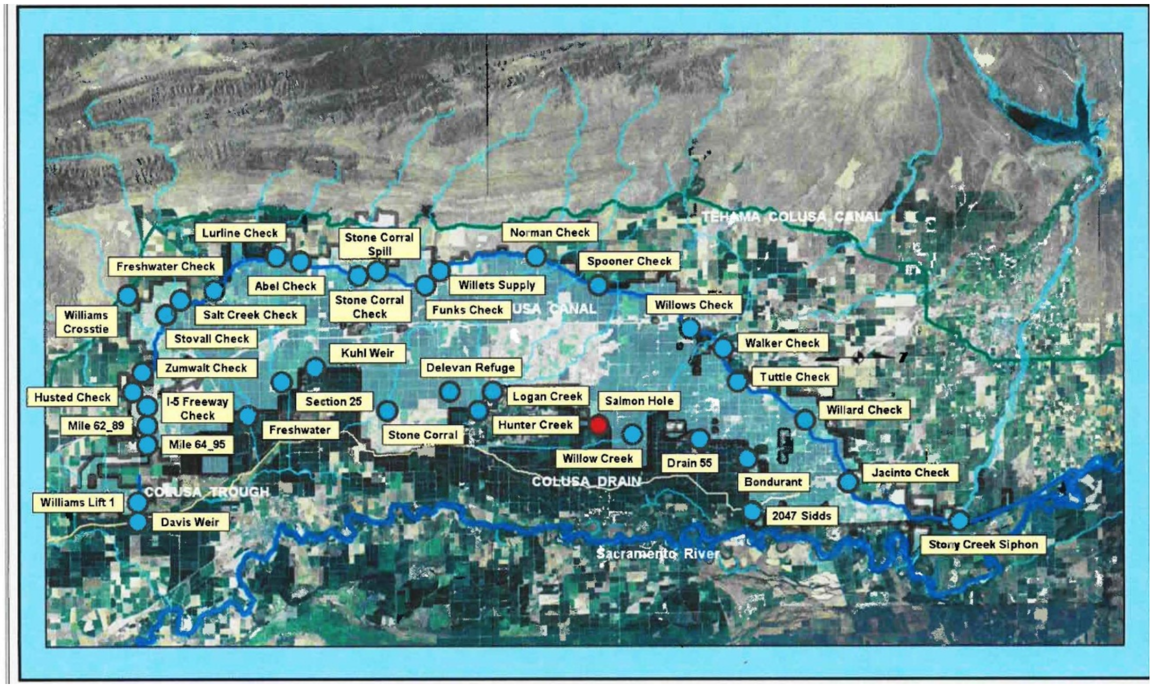

Figure 4. Currently monitored SCADA sites

Project Considerations

After completion of the design phase by ITRC, the next task was to select an integrator to perform all the technical phases of the project. During the selection process, potential integrators with extensive knowledge in the SCADA field were asked to provide a list of similar projects that they have been involved with, and their work experience was carefully reviewed. Another consideration was ensuring that the company is an established business that will be available to consult in future years.

GCID learned that conducting a radio survey and confirming that the proper radio system was selected was very important. Failure to do this early in the process resulted in time delays and increased costs. While the integrator supplies the necessary information, it is essential to review the decisions based on the technology of the District’s system and the area. Deciding what types of SCADA operating screens will be optimal for the system early in the process saves time and effort as the integrator can design them as specified, avoiding the need to alter screens at a later date.

After the completion of the SCADA project, the system requires annual maintenance on all the components. This can be accomplished by establishing an annual maintenance agreement with the integrator, or training personnel to perform these duties. GCID elected to train personnel who conduct inspections and maintenance on the entire system, and consult with the integrator as necessary.

Careful selection of the types of components used as part of the SCADA system, can save time and expense. It is beneficial to avoid the use of proprietary equipment and to choose “shelf items,” so that when components inevitably fail there is not a need to wait for specialized parts that are not readily available. Another area to consider during the planning phase is whether there is capacity to expand the SCADA system in the future, as it can be very costly to expand and replace the existing equipment with components that could have been used during the initial installation.

GCID employs a variety of flow measurement methods, ranging from continuous recording ultrasonic acoustic velocity meters to once-per-day weir depth measurements. Here, too, measurement has evolved to support routine water operations and administration, with primary emphasis on Sacramento River diversions and secondary emphasis on major internal operations (flow division) sites and drain outflows.

GCID recently completed a comprehensive evaluation and ranking of existing and prospective flow measurement sites that considers site importance, the annual volume of water passing the site, and measurement cost. Highest priority was placed on large, currently unmeasured operational and boundary measurement sites. Identified flow measurement improvements will be implemented over a period of several years.

CHALLENGES

One of the challenges canal operators face is the timing of pump changes as they relate to demand. Prior to the installation of the SCADA system, canal operators would either store water in selected pools along the canal or intentionally lower pools depending on the water orders for the next day. This resulted in fluctuating water elevation in the canal that caused laterals to either spill excess amounts at the end of the lateral, or short the lateral and interrupt service to the water user until the canal pool elevation returned to its original elevation. One of the positive aspects of the SCADA system is that it moves water up and down the canal more quickly and maintains the same water elevation at each check. This is a better result than the operators could accomplish by moving the water manually. Canal operators now make pump changes and are able to conserve water and maintain constant flows into fields, and the only remaining issue is to resolve the timing of when to make the changes with the SCADA system to achieve the best results.

Water velocity in the canal varies between 0.2 feet per-second during low flow condition, and 4.0 feet per-second, during high flow conditions. The period of time it takes the water to move 65 miles down the main canal increases during high demand periods and decreases during the low demand periods. It is imperative that the timing of increasing or decreasing river diversions is precise and has always been a difficult part of operating the system. The SCADA system provides the ability to adjust water elevation targets in selected areas, and helps to prevent either drying up the bottom of the conveyance system or spilling an excess amount of water.

Adjusting the water level sensors to accommodate water levels during the off-peak season has been one of the challenges of fine-tuning the system. Maintaining redundant sensors for water elevations has proven to be time consuming as discrepancies result in continual adjustments and unnecessary alarms. The strategic placement of stilling wells and accurate calibration of sensors to cover all flow conditions has been an important part of achieving proper operating parameters.

Calibrating gate position sensors is as challenging as calibrating water level sensors. Having a stationary gauge mounted above the water level on each water control gate allows for occasional site visits to actually confirm gate positions with gate sensors. Gate position is critical because the flow at each check structure is based on head pressure versus gate opening. As canal operators started to fill the canal system in spring 2011 and prepared each SCADA site for full automation, it was soon apparent that the flows at each site were not calibrated properly. Once the canal was filled with water the gate openings could not be measured accurately to verify the redundant sensor positions.

The majority of the District's SCADA sites are located in rural areas that experience frequent power outages. In most instances, the SCADA technician has been able to reset fuses or change batteries at the site. However, in some cases it was necessary for the technician to call the integrator to receive direction on how to fix the problem. Some of the older check structures had inadequate electrical equipment, and as the SCADA program constantly moves the gates up and down to maintain a constant water elevation, stress was placed on older components. Eventually the older components were overloaded and would fail, resulting in an alarm being triggered and water elevations not meeting the target. This equipment will be updated and replaced in the future.

DATA ACQUISITION AND MANAGEMENT BENEFITS

While SCADA has resulted in better control of the conveyance system, GCID considers the data acquisition, the management and use of that data to be equally important. In fact, the communication requirements, system architecture, and data-carrying capability of the District's SCADA system were weighed equally to the need for automated control in order to meet the current and future reporting and accounting guidelines at the District, regional, state, and federal level.

Water Measurement Reporting and Water Balance Model

As discussed previously, GCID has converted to a data base environment to accommodate the growing volume of operational data. With its system in operation, GCID is now looking to use data directly from SCADA to populate its Annual Report. Eventually, GCID intends to house or access all of the data needed for water balance analysis in an integrated Water Information System (WIS). A major consideration in the design of the WIS is to enable routine updates of the water balance model.

The objective of the water balance model is to enhance the value of the data presented in the Annual Report by augmenting and combining it in the form of a water balance that accounts for all water entering, leaving and stored within the District over specified periods of time. Beyond tracking trends in certain individual operating parameters, the water balance will allow GCID managers to assess historical operational performance under different water supply and demand conditions. The main outcome from the water balance will be an improved understanding of GCID system characteristics and operational performance, which, in turn, will provide an improved basis for identifying, assessing and planning potential water management and facility improvements. It is also expected that the water balance will reveal opportunities to improve GCID's water measurement and data management processes.

A particular purpose in developing the water balance is to characterize exchanges of water between GCID canals, laterals, drains and irrigated lands and the underlying groundwater system through the processes of recharge (by canal seepage and deep percolation of applied water) and discharge (groundwater pumping). It is generally accepted that the diversion and application of surface water in GCID results in appreciable net recharge to underlying groundwater aquifers. The water balance will help to improve recharge estimates, and will improve GCID's ability to manage underlying groundwater, including improved calibration of groundwater models.

GCID is currently developing the database component of SCADA so that measurements will feed directly into the Water Balance model, thus eliminating the need to transcribe data into the model, which is time consuming and prone to error. Additionally, GCID will also be able to generate its Annual Report data directly from SCADA.

Legislative Mandates

As mentioned previously, California's policy makers have and will continue to enact legislation requiring agricultural water suppliers (irrigation and water districts) to prove that agricultural water use is efficient and beneficial. In 2009, the legislature passed and the Governor enacted a Comprehensive Water Package that required water agencies to: i) report surface water diversions to the State Water Resources Control Board; ii) monitor and report groundwater elevations to show the health of groundwater basins; iii) provide measurement and volumetric pricing to customers; and iv) quantify agricultural water use efficiency.

Surface Water Diversion Reporting. In 2009, the California Water Code was modified to require diverters, including pre-1914 water right holders, to file Statements to measure their monthly water diversions beginning in January 2012. California Water Code section 5103 subdivision (e)(1) states the following:

> *"On and after January 1, 2012, [each statement shall include] monthly records of water diversions. The measurements of the diversion shall be made using best available technologies and best professional practices."*

GCID's SCADA system includes real time monitoring of surface water diversions, including water quality, at its Hamilton City Pumping Plant (HCPP) from the Sacramento River. Currently, fifteen minute data from the HCPP diversion is collected by SCADA; this information is averaged daily and then sent to GCID's Annual Report via SQL server. This information can also be pushed externally to the District's website.

SCADA offers the potential for the entire Sacramento River system to be managed and monitored on a real-time basis. If funding were available to allow other local agencies to install SCADA on their delivery systems, data could be pushed from locally owned, operated, and maintained SCADA systems to a centralized database and operations center that would allow more real-time operations. For example, the Central Valley Operations (CVO) center of the Bureau of Reclamation operates the Sacramento River system from Shasta Reservoir to the California Delta. GCID, along with other Sacramento River Settlement Contractors (SRSC), diverts water between Shasta and the Delta. If real-time SCADA systems existed on all of those diversions, the SRSC and the CVO could jointly operate the system more efficiently to minimize operational losses. While all the SRSC diversions are measured, most do not have an active SCADA system; however, if funding were made available most water agencies would add SCADA to their existing systems.

Groundwater Monitoring and Reporting. In addition to the surface water diversion reporting, the State Legislature amended the Water Code with SBX7-6, which mandates a statewide groundwater elevation monitoring program to track seasonal and long-term trends in groundwater elevations in California's groundwater basins. To achieve that goal, the amendment requires collaboration between local monitoring entities and the Department of Water Resources (DWR) to collect groundwater elevation data. Collection and evaluation of such data on a statewide scale is an important fundamental step toward improving management of California's groundwater resources.

In accordance with this amendment to the Water Code, DWR developed the California Statewide Groundwater Elevation Monitoring (CASGEM) program. The intent of the CASGEM program is to establish a permanent, locally-managed program of regular and systematic monitoring in all of California's alluvial groundwater basins. The CASGEM program will rely and build on the many established local long-term groundwater monitoring and management programs. DWR's role is to coordinate the CASGEM program, to work cooperatively with local entities, and to maintain the collected elevation data in a readily and widely available public database.

To comply with this legislation, GCID volunteered to become a local monitoring agency for groundwater elevations within its service areas, which also includes significant portions of Glenn and Colusa counties. Historically, these wells were monitored by GCID staff in the spring and fall of each year, and for those multi-completion monitoring depths, a data recorder was used that measured water levels on a 15-minute interval and was downloaded on monthly intervals.

GCID’s SCADA system now allows for these well sites to be measured remotely, with on-off control being a future option. The data collected and pushed to CASGEM is also pushed to GCID’s Annual Report, which significantly reduces the time required for GCID personnel to perform the monitoring, and also minimizes the possibility of data being reported incorrectly.

Measurement and Volumetric Pricing to Customers. Also legislated in 2009, California Water Code §10608.48(i)(1) requires the Department of Water Resources to adopt regulations that provide for a range of options that agricultural water suppliers may use or implement to comply with the measurement requirements in paragraph (1) of subdivision (b) of §10608.48, which states:

> "Agricultural water suppliers shall implement all of the following critical efficient management practices:
> (1) Measure the volume of water delivered to customers with sufficient accuracy to comply with subdivision (a) of Section 531.10 and to implement paragraph (2).
> (2) Adopt a pricing structure for water customers based at least in part on quantity delivered."

To comply with this legislative mandate, GCID is expanding its SCADA system to measure all laterals and other larger diversions from its main canal, which will interrogate flow meters on a real-time basis. Measurement records will be batched to the *Water Measurement Report* to provide for a complete record of District deliveries, and then to the Water Accounting Program that will be used to generate water user billings. The acreage and cropping pattern in each lateral service area is available in GIS format allowing for exact determination of acreage and crop type within each service area. This information is obtained from water users during the water application process and then is confirmed by District personnel during mid-year field inspections.

The Water Accounting Program will utilize the information from SCADA and the crop information from GIS to develop an application rate (acre-feet/acre) within each service area that will satisfy the pricing requirement based on "in part quantity delivered." GCID also charges land and crop based assessments in addition to the volumetric charge.

<u>Quantification of Agricultural Water Use Efficiency</u>. Quantifying the efficiency of agricultural water use was directed by policy statements and other language in the 2009 legislation – SBX7-7. Specifically, §10608.64 of the Act states that the Department of Water Resources shall develop a methodology for quantifying the efficiency of agricultural water use and shall report to the Legislature on a proposed methodology and a plan for implementation. The plan shall include the estimated implementation costs and the types of data needed to support the methodology.

One approach for quantifying the efficiency of agricultural water use is to focus on the elements of a water balance (accounting) within an established boundary; for GCID it would be the District boundaries. Using SCADA, GCID is able to measure and record all sources and dispositions of water into, within, and out of a defined boundary. From these water flow elements, various relationships can be evaluated to describe the current water management conditions and assess opportunities for change. As described previously, GCID has developed a water balance program, and SCADA will be a vital tool in quantifying efficiency at the district-scale level.

CONCLUSION

The total initial cost of the SCADA project is currently about $2.7 million; however, GCID expects this cost to increase as more sites are added. While an expensive investment, GCID is adding tools to the toolbox that will improve conveyance system efficiency, conserve water, improve water quality by reducing Sacramento River diversions by approximately 40,000 acre-feet annually, improve river water temperature to benefit the endangered salmon, and conserve roughly 500,000 KWH annually. From a data perspective, it is now possible to collect real-time, historical, relational and transactional data to create a single virtual data resource that can access, aggregate, correlate and present role-appropriate information to canal operators, supervisors and management. Not all benefits have been realized in the short period of time that SCADA has been implemented, but it is anticipated that in future years GCID will meet and possibly exceed all the primary objectives.

The 2011 irrigation season was the first full season in which GCID operated the main canal in the fully automated position. The benefits were apparent in that service to the growers increased, and fewer man-hours were needed to operate the canal system. SCADA has enabled the District to meet all public policy requirements, while continuing to adhere to the District’s mission statement of delivering a reliable supply of water, while protecting the environment and economic viability in the region.

INFORMATION SYSTEMS IN WATER SECTOR OF CENTRAL ASIA: CHALLENGES AND PERSPECTIVES

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ABSTRACT

A water resource planning for the river basins is the most crucial element of Integrated Water Resources Management (IWRM) approach. Development and implementation of the river basin plans enables water management organizations to cope with increasing uncertainties due to climate change, sectoral competition and population growth. Contemporary water management decisions use many sources of information and forms of data. However, the data and information on water sector is often dispersed, heterogeneous, incomplete, and not comparable. New social and political realms require a participatory involvement of the different stakeholders for decision making process in water sector. Thus open source, easy to access information and data management systems are successful. The aim of this paper is to present practical results on improving water management in Central Asia through application of information and communication technologies at the operational level across diverse institutional settings, i.e., transboundary, watershed and national levels of the region. The case study presented is conducted within framework of Transboundary Water Management in Central Asia programme. The programme is the part of the 'Berlin Process', an initiative by the German Federal Government to support the countries of Central Asia in water management and to make water a subject of intensified transboundary cooperation.

INTRODUCTION

Central Asia is a home of more than 55 million people, landlocked region with an extreme continental climate of 10 fold difference between rainfall (150 - 300 mm) and evaporation (1200 - 1600 mm) (Dukhovniy and Sokolov 2003; UNDP 2005; UNEP 2005). In addition climate change impacts have been serious on ice caps in mountains (World Bank 2009). These all make availability of water resources at least contested issue (Abdullaev et al. 2010). Five Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) are sharing two large rivers (Amu Darya and Syr Darya) and a complex irrigation system, covering around 8 million ha of irrigated lands (Figure 1).

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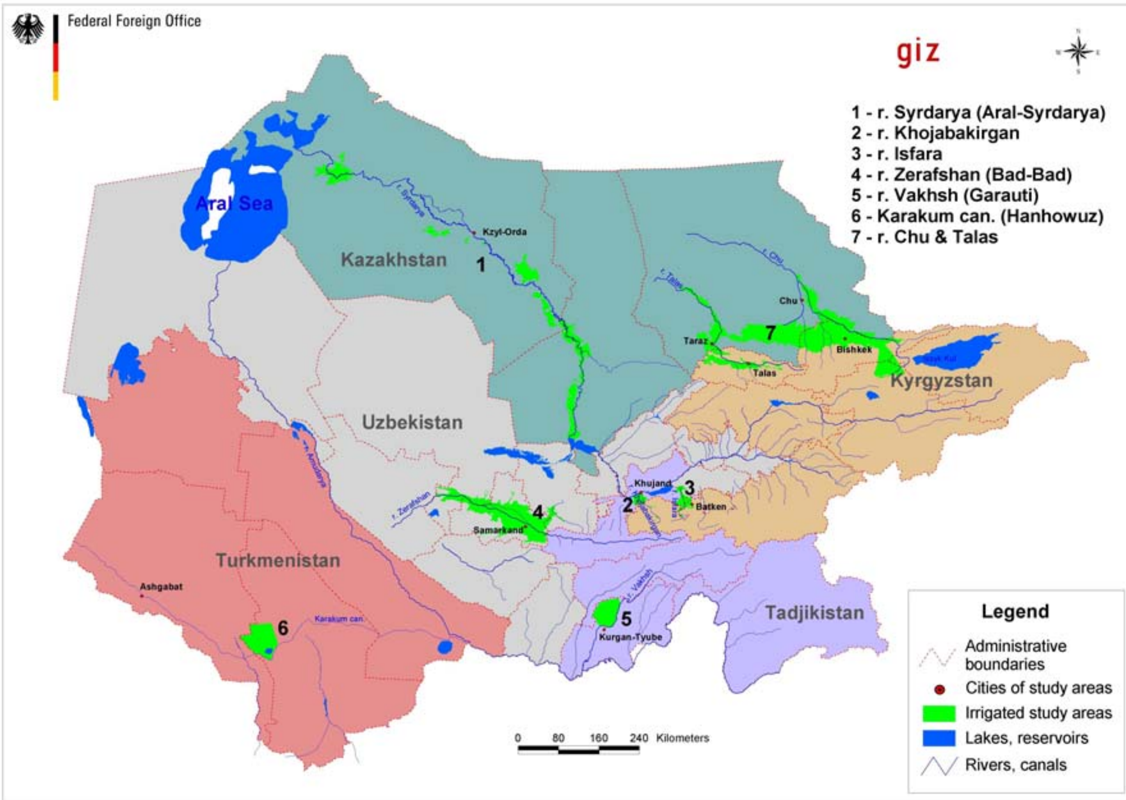


Figure 1. Map of Central Asia and location of intervention pilot areas

Both rivers start in upstream countries with most of the reservoirs and hydropower facilities, yet irrigation is largely practiced in downstream countries (Rakhmatullaev et al. 2010). Previously, this complex system was governed with a single set of policies defined by Moscow. After the collapse of the Soviet Union, states are facing growing tensions over the water resources (Murray-Rust et al. 2003).

During the Soviet times information on water management and use has been handled through administrative reporting system from lowest water management organizations towards higher ones. The soviet legacy in the new Central Asian independent states still practice high reporting requirements and documentation styles, the water sector is not exception. The numbers of reports produced by water management organization (WMOs) were large and mostly in formats which were not accessible or understandable for general public (Murray-Rust et al. 2003). Annual reports have been produced by each WMO and stored in the archives at least for 5 years. Based on annual reports of WMOs and statistical data collected by national departments of the statistics year (annual) books have been published for each soviet republic. The yearly statistics books are composed of data on water resources management: water use per sector, per capita and per administrative units (province).

The water resources assessment and planning, operational decision making in water sector uses the data from different sectors, uses, users and water sources (Biswas 2008). Meanwhile, the crude data are still kept at the lower levels of water management with restricted access to the higher water management hierarchies and to the public. Old ways of collection, storing and processing of the data and information does not work in new context of post- soviet developments such as democracy, market economy declared by Central Asian states (Abdullaev and Rakhmatullaev 2011).

According to Garcia the water governance and management can be divided into three interlinked levels i) constitutional, ii) associative and iii) operational (Garcia 2008). The real-term data are produced at the operational level of water management. At this level, complex interactions between different actors (WMO, Water users associations, farmers, industry, local government authorities, etc.) on water management took place to define water rights (limits), water distribution and water control with application of different water control strategies (Aminova and Abdullaev 2009). Therefore, improving of data management at this level is a crucial precondition for improving of water governance at both in this and higher levels (national and regional) of water management.

The recent advances in information communication technologies (ICTs) and their unprecedented applications in era of globalization have created enormous opportunities for developments of e-government systems around the globe. E-government paradigm is believed to serve as bridge between the governments and their citizens for intensification of dialogue. According to UNDP one of the indicators that can be measured for assessment of governments to use ICTs is e-government readiness index. E-government readiness index is "a composite measurement of the *capacity* and *willingness* of countries to use e-government for ICT-led development" (UNDP 2008).

According to the United Nations statistics, the Central Asian region has made the most significant improvement in e-government development as a region but still a slightly below the world average (UNDESA 2011). Table 1 depicts the statistics of e-government developments and world ranking of Central Asia countries.

Table 1. E-government readiness index and world ranking of Central Asian countries (UN DESA 'E-Government Readiness Knowledge Base', 2011)

Country	**E-government readiness index***		**World E-government development ranking**		
	2008	**2010**	**2008**	**2010**	**Change**
Kazakhstan 0.47	43	0.5578	81	46	+ 35
Kyrgyzstan 0419	5	0.4417	102	91	+ 11
Tajikistan 0.31	50	0.3477	132	122	+ 10
Turkmenistan 0.32	62	0.3226	128	130	- 2
Uzbekistan 0.40	57	0.4498	109	87	+ 22
World average	**0.4406**	**0.4514**	**Total number of countries =192**		

*E-government readiness index is composed of i) web measure index; ii) telecommunication infrastructure index; iii) human capital index

Almost all counties except Turkmenistan did progress in implementation of e-government systems with Kazakhstan as a regional leader. Thus it is one of pre-conditions to implement data management interventions in water resources sector of the region.

MATERIALS AND METHODS

Conceptual framework

The ultimate goal of the data management activities is two-fold. The first objective is to provide technical capabilities for improving decision making process at lowest possible water management level (operational) and the second aim is to enable WMOs to carry out river basin plans. Yet few outstanding issues are to be addressed such as water governance and knowledge management. The first issue is related to the accuracy of the data (quality control), the second is absence of the indicators for water management performance assessment and the third issue is concerned with regular and reliable data collection and mining. Data management for IWRM activities was designed with four interlinked intervention pathways: (i) principles, (ii) data, (iii) hardware and (iv)software (Figure 2).

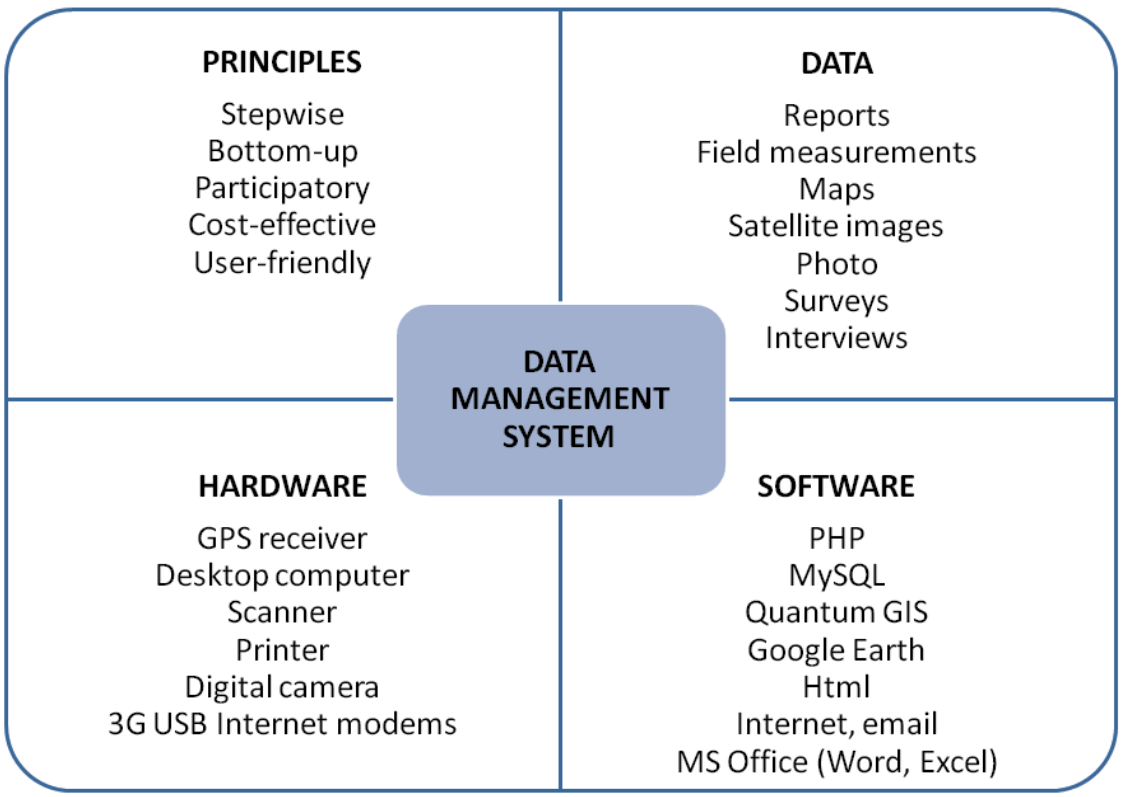


Figure 2. Main components of Data management

Strategic approach

Activities on the Data Management have been designed of a bottom-up approach with full involvement of the partner WMO into the activities from the very beginning (pre-assessment and planning stages). Partner WMO have decided on type, structure, content, interface and format of the Data Management tools which created an ownership of a process by partner WMO.

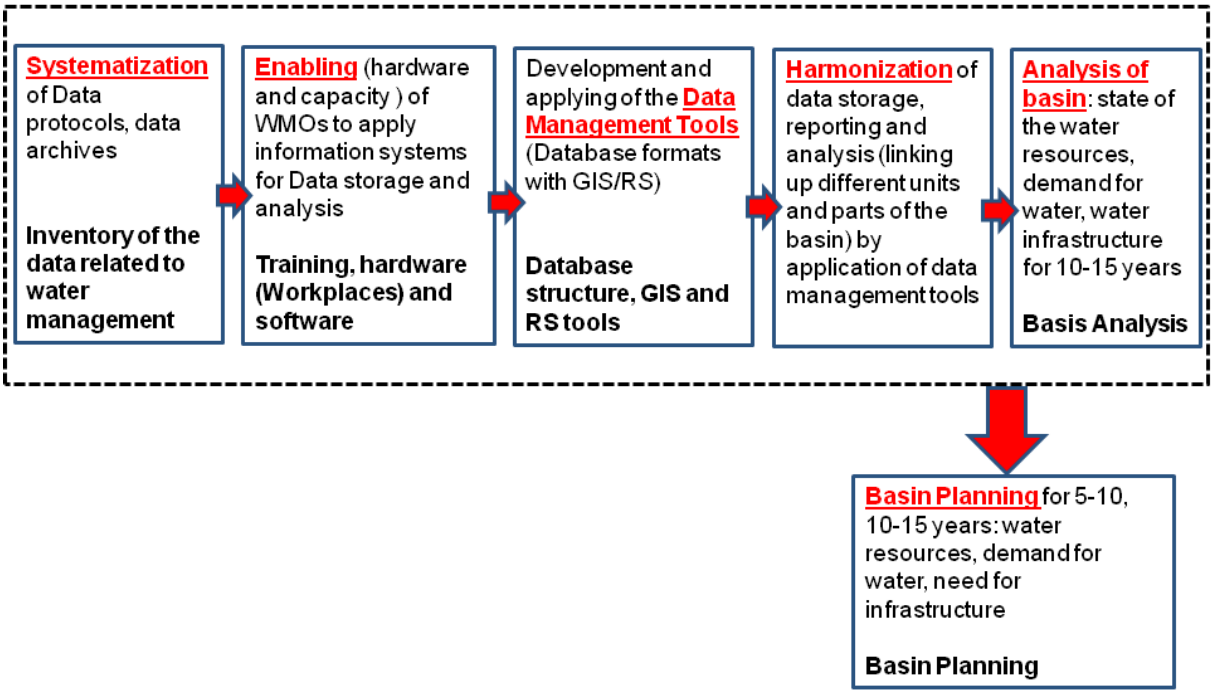


Figure 3. Logical framework of data management activities for river basin planning

Systematization. The initial step was to conduct comprehensive pre-assessment of hardware and capacity building needs of local WMO through baseline surveys and field visits to intervention localities. One of the main aspects was to review the existing data reporting systems and protocols used. In addition, physical infrastructure was also examined for assessing storage, retrieval and communication facilities at place.

Enabling Environment. Special workplaces on data base and GIS/RS were established with providing up-to-date hardware and software to partner WMO at their facilities. Most importantly, those workplaces have been linked with various units of the WMO such as dispatch center, water planning unit and other relevant departments through a local network. These networks helped to improve accessibility and operation, filling data onto the database, i.e., most importantly the transparency of the process.
Implementation of capacity building activities were carried out to educate experts of partner WMOs in all 7 selected sites on data management. The topics of such training series were introductory courses on GIS, GPS, satellite imageries (Google Earth, DEM) and remote sensing tools application in water sector. The partner WMOs have nominated one water professional involved in daily data handling and one expert/scientist from local research organizations or universities (outsiders from water) with knowledge of data management. The capacity building activities continued with a series of on the job trainings in all selected sites. During the on the job trainings, supplemental training needs were indentified, e.g., use of Internet and GPS receivers.

Data management tools. The *Database* has been designed to store and use of the digital data on water resources, use, hydraulic facilities, hydrological conditions, economic and administrative conditions of the location (basin, irrigation system). Datasets are at present available in different formats (MS Excel, Word, Access and etc.), could be transformed into the database by import/export commands or manual typing.The database has been developed using open-source PHP which stands for "*PHP: Hypertext Preprocessor*" script language, is at present commonly used for web based databases (PHP 2011). The foundation platform was MySQL® is a freely downloadable version of the world's most popular open source database (MySQL 2011). It is especially suited for web development and can be embedded into HTML (Hypertext Markup Language). This programme language allows inserting additional tables and updating data base by trained experts of WMOs without aid of programming specialist.

The *Geographical Information System (GIS)* and *Remote Sensing (RS)* tools will allow assessing present irrigated areas, water use situation in different parts of the study areas (basin, irrigation system) (Bastiaanssen 1998). The GIS tools include use of satellite based images, Digital Elevation Models (DEMs), different background maps and coordinates of water infrastructure, recorded through GPS receivers. ArcGIS 9.3.1® (Russian version) used for preparation of raster and vector layers and ERDAS Imagine® program was used for image processing and land use map development. Application of the GIS and RS tools to assess size and location of the irrigated areas is a most important contribution to improve water resources management planning and allocation, especially in Central Asia, where irrigation contributes up to 90% of water use and transboundary conditions.

Harmonization. The measures are focused on development and implementation of the database system architecture with full ownership by local WMO in terms of content, format, and interface. In this stage, WMO partners provided algorithms for reporting on daily water information. User's manuals on database operation and GIS were developed as supportive documentation for users. Most importantly, the manuals were developed with reflections of end user ideas in non-technical fashion and language. Another paramount issue was to harmonize developed databases for all respective intervention sites in terms of functionalities, modes and structures, i.e., database compatibility in all locations. That is the database structure in different locations could produce comparable reports or indicators that in future data exchange would be possible in future.

Basin plans. The activities were concerned with the filling of the database with retrospective and operational data on water discharge, use, abstractions, population dynamics and irrigation. The last step is to prepare river basin plans based on the stored and generated data.

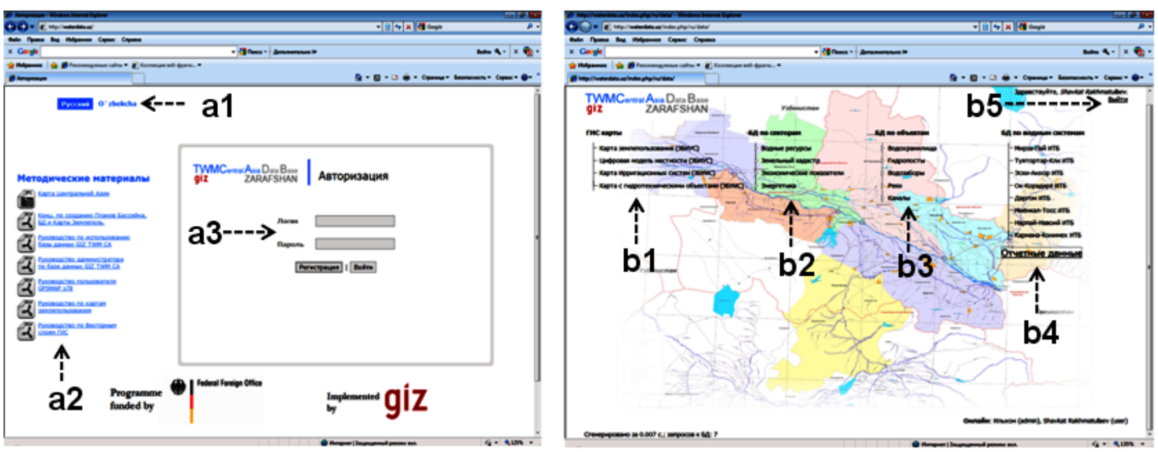
RESULTS AND DISCUSSION

Political support

The most crucial element for successful implementation of the data management activities is a political support from national water management agencies/ministries in each Central Asian country. Therefore, database concept and structure has been presented to the respective national authorities to gain a political support. This also has been important for the integration of the database into the normal business procedures of the partner WMO. The national authorities of Kyrgyzstan, Uzbekistan, Tajikistan and Turkmenistan have issued support letters to the programme indicating their desire to support the Data Management activities. In 4 above mentioned countries, special decrees were issued by the respective national water authorities declaring to use of the database as a main tool for reporting within their respective hierarchical systems in all states. In Kazakhstan government is funding such program. Moreover, there are attempts by national governments in Central Asia to reduce substantially paper reporting by promotion of electronic reporting.

Database

Architecture. The database structure reflects most of the desires and requirements of partner WMOs on regular reporting. Database allows the production of a selected set of regular reports. In order to ease operation by local experts in their daily work the database made as bilingual, with Russian and a local language as choice. User-friendly interface and easy functioning menu were major requirements to the database from WMO experts. This could avoid costly upgrading of the database. In partner WMOs, soviet time data protocols and formats are used with translation into national languages. This has been achieved through the application of genuine components for databases in all sites (Figure 4).



a) b)

Figure 4. Interface and architecture of database

a) Interface of main page of database; a1 – Language versions; a2 – Help menu; a3 – Login and password;
b) Architecture of database; b1 – GIS based maps; b2 – dataset of sectors; b3 – dataset of hydraulic infrastructure; b4 – reporting forms and protocols; b5 – Administration and management menu

Access/Connection. Access to the database has been one of the crucial issues showing how it will be difficult to convince WMOs to give an open access to the public or to “outsiders”. Only one partner has agreed during the initial meetings to post database onto the internet. After a few rows in the meetings, other WMOs agreed to launch internet database with the provision of access only to their staff from branches/units. Access to the developed database is restricted for only staff of respective WMOs at the moment. One of the reasons is that central server (dispatch center) operator will see who is online and entering data. In addition, the databases are functioning as pilot tests within single WMOs. In four countries from 2012 the database will be used in day-to-day operations. Another concern of WMOs is security reasons.

Administration. Other important issue is ability to administer database itself. The administration menu was incorporated into the database for full control by national WMOs. This aspect played important and trustworthy preconditions for successful implementation. The menu enables WMOs to update, delete or change the structure of database and most importantly to control the access to the database via user registration.

Data compilation. Data bases have been filled by retrospective data of 5 years (2005-2010) and actual data for the 2011 by trained experts of the WMOs. However, it turned to be difficult task to collect long term, retrospective data due to the lost of the paper reports which were stored in unfitting conditions at the offices of district (rayon) and provincial (oblast) water management organizations. This once more confirmed a need for introduction of data management tools to transfer all data into the data bases.

Knowledge Management. The success of the data management activities in long run depends on how expert knowledge transferred from those of trained staff to other personnel of WMOs. The institutional learning is one of important preconditions for successful data management interventions (McDonnell 2008). However, internal structure of partner WMOs at present does not support institutional learning. Therefore, more on job trainings has been planned to contribute into capacity building within WMOs.

GIS and RS tools

Application of GIS tools for water resources management has been quite successful from research and business point of view (Pickles 1995; Bastiaanssen 1998; Ozdogan et al. 2010). However, due to high prices and high learning requirements for GIS tools, their application in practical water management has been limited. However, recent changes in GIS approaches, automation of operations used in GIS, free of charge or low cost satellite images, open source software made GIS tools more attractive for the water sector. The assessment of irrigated areas is important for effective water management for the Central Asian region where irrigation contributes up to 90% of water use (Chemin et al. 2003; Conrad et al. 2007). The irrigated area maps helpful to indentify actually irrigated areas demand for water and water use in specific locations.

Professional GIS/RS consultants have been recruited to produce land use – land cover maps (LULC) for the selected pilot sites. The publicly available data sources have been used for the preparation of the LULC maps. The Landsat-5 satellite images were downloaded from Internet (http://glovis.usgs.gov/) for peak of the growing season (July-

September) of 2009. The processing of the images has been completed by experts with on the job training for staff of WMOs. On the other hand, WMO experts have collected and digitized different maps for GIS layers of irrigated areas such as topographic maps, administrative borders, irrigation system borders, etc. The maps were manually digitized; using as background layer Landsat satellite images (Figure 5).

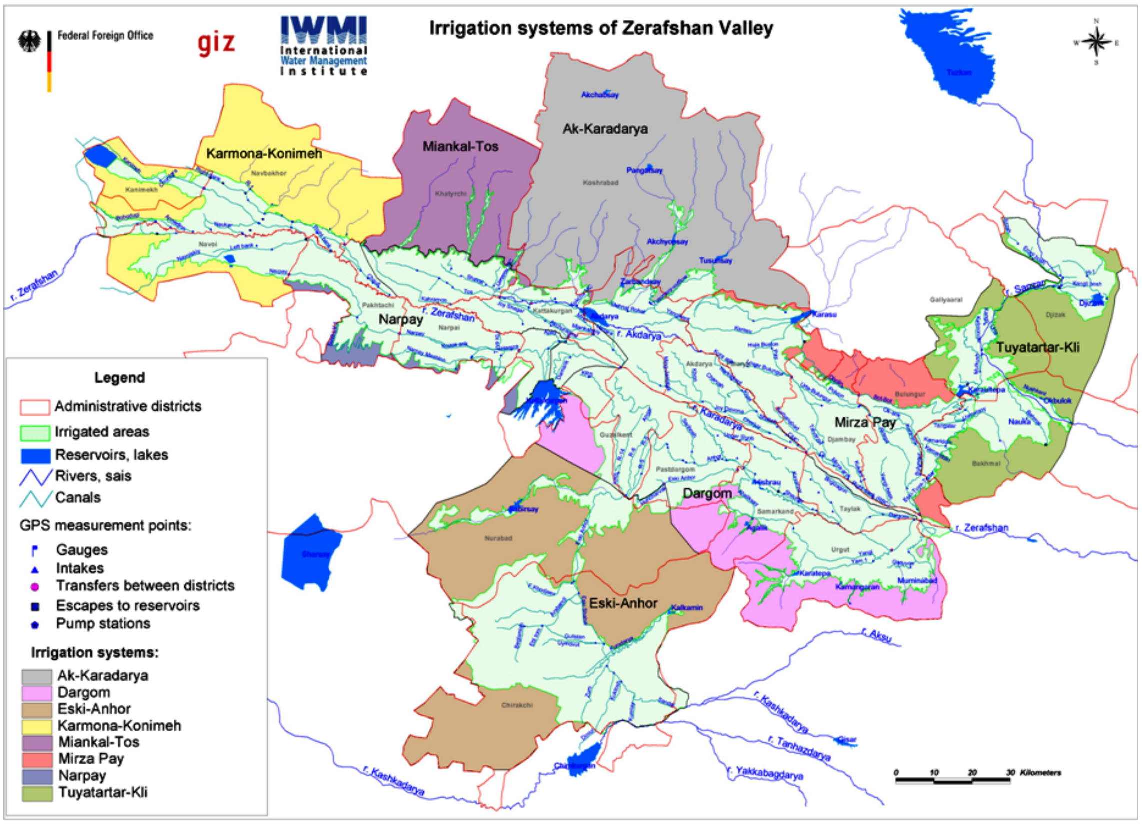


Figure 7. GIS map of hydraulic infrastructure and irrigation districts of the Serafshan River Basin (Uzbekistan part)

The publicly available Aster Digital Elevation Model (DEM) with spatial resolution of 30 meters raster layers were downloaded from Internet (https://wist.echo.nasa.gov/) for all intervention areas. The DEM were used for manual delineation of basin boundaries in the water formation zones (at high altitudes) for study areas. The basin boundaries at low altitudes further corrected with use of the water infrastructure locations. Further, the free of charge products (MOD13Q1) of MODIS satellite images which represent the

Normalized Difference Vegetation Index (NDVI) values (with spatial resolution 250 m and temporal resolution 16 days) were downloaded from Internet (http://glovis.usgs.gov/). NDVI indices were used to indentify land use classes. In situation, when the number of Land Use/ Land Cover classes inside the study areas was unknown, unsupervised classification with predefined number of classes. Unsupervised classification with 16 classes of land use was applied separately to images of each study area. At present Land use and Land cover maps are produced for 4 intervention locations out of 7 (Figure 6).

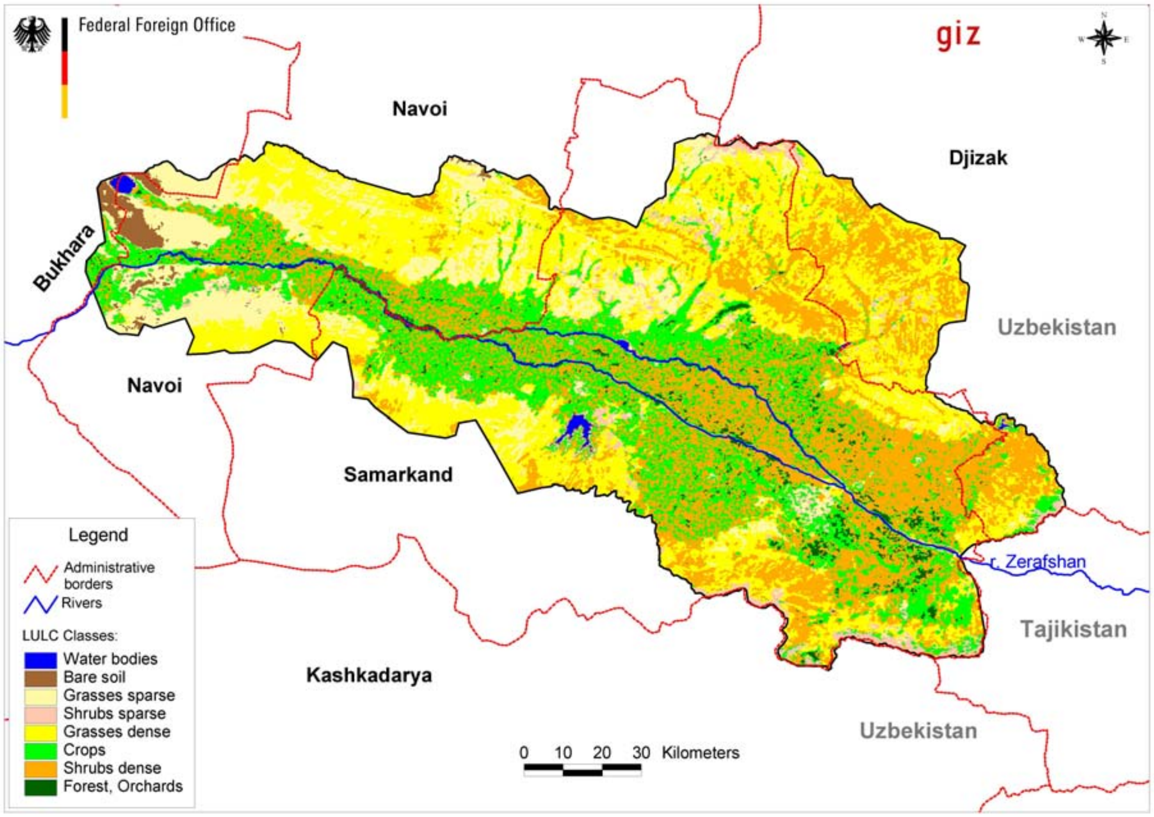


Figure 6. Land Use/land Cover classes of the Serafshan River Basin (Uzbekistan part)

GIS and RS tools are differing from data base due to quite high requirements for the experts who will work with these tools. Without a special training and long term experience local experts cannot produce GIS tools. However, LULC maps are not required to be prepared for each season or year but rather updating it every 4-5 years will be sufficient for basin assessment and planning purposes. Keeping a professional staff with GIS skills is not feasible in current conditions due to the low wages of WMO staff. Therefore, recruiting of a growing number of companies or experts on GIS is an option for updating of the LULC maps. However, in a few Central Asian states National Water Management Authorities are starting to set up GIS units at the national level which can help WMO to produce LULC on a regular basis.

CONCLUSION

Since 1991, independence from former Soviet Union data and information collection, reporting requirements in water sector of the Central Asian countries has not been changed too much from Soviet legacy. The preliminary results of the data management for IWRM activities have shown acknowledgement of the need to use modern information and communication technologies into decision making process and daily operation of national water management systems for sustainable and efficient water management (GWP and INBO 2009). The data previously scattered around different water management levels are gathered and systematized, made accessible for water professionals and decision makers. The water professionals of WMOs are able to produce their regular weekly, monthly and annual reports from the online database.

DM for IWRM activities in selected sites shows that there is DM for IWRM activities are still ongoing and therefore it is action in progress and more learning will be available upon completion of the activities. Yet there are still many challenges on practical application of data management tools in Central Asia, including:

- Diversified understanding of advantages of information technologies across Central Asian staff and decision makers of WMO
- Staff of WMO are generally technically inexperienced on database, GIS and RS tools
- The sub-basin WMO are often geographically dispersed and Internet/Intranet logistics should be carefully examined
- Digital databases should be stored centrally with full access to different users via Internet
- Internet infrastructure is poor for acquisition of large size satellite imaginary.

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CLIMATE AND ET: DO PLANT WATER REQUIREMENTS INCREASE DURING A DROUGHT?

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David Smith[2]
Dr. Guy Fipps[3]

ABSTRACT

Municipalities, engineering consultants and State agencies use reference evapotranspiration (ETo) data (directly and indirectly) for long-term water planning, for designing hydraulic structures, and for establishing regulatory guidance and conservation programs intended to reduce water waste. The use of ETo data for agricultural and landscape irrigation scheduling is becoming more common in Texas as ETo-based controllers and automation technologies become more affordable. Until recently, most ETo data has been available as monthly values averaged over many years. Today, automated weather stations and irrigation controllers equipped with specialized instrumentation allow for real-time ETo measurements. With the expected rise in global warming and increased frequency of extreme climate variability in the coming decades, conservation and efficient use of water resources is essential and must make use of the most accurate and representative data available.

BACKGROUND

2011 marked the driest year on record in the State of Texas with over 81% of the state experiencing an exceptional drought by the end of August (See Figure 1). Compounding the lack of rainfall was record heat during the summer of 2011. Observations from the TexasET Network and Website (http://TexasET.tamu.edu) showed higher temperatures, lower relative humidity and higher wind speeds than typically experienced during the spring and summer months, resulting in 25% to 50% higher ETo rates than historic averages during 2011. The implications are quite serious, as most current water planning and drought contingency plans do not take into consideration increases in ET during such periods, and irrigation planning and capacity sizing are based on historic averages of consumptive use.

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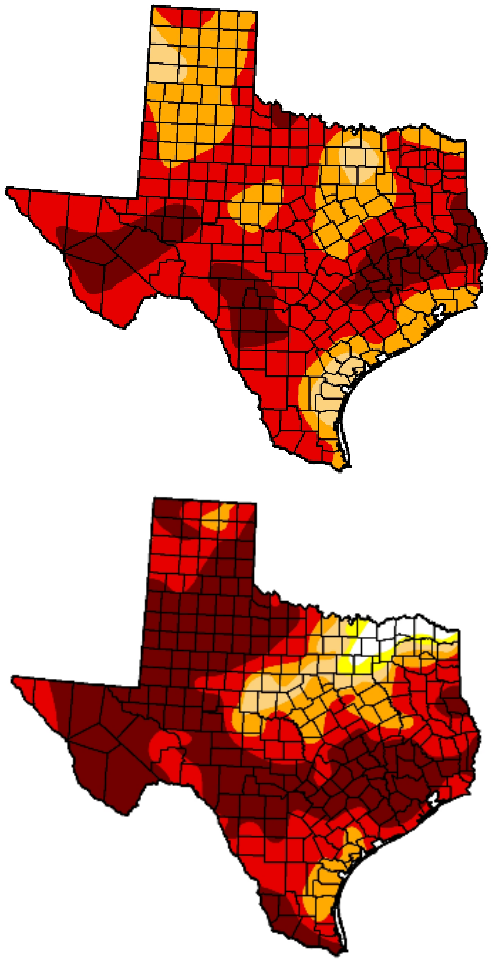
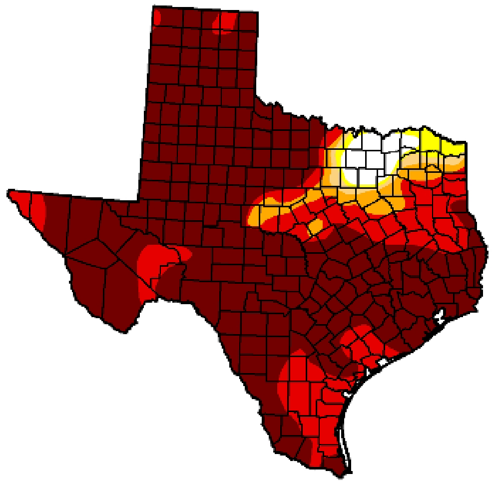
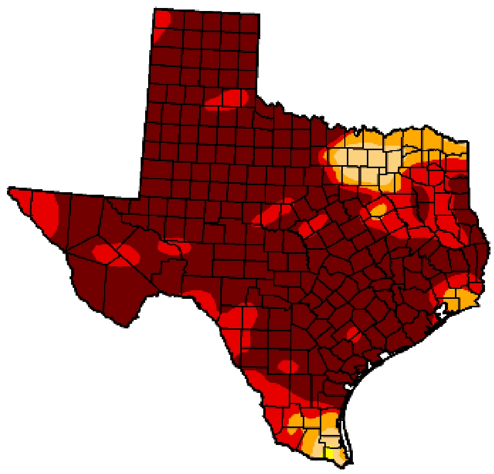
Figure 1. US Drought Monitor, Texas. April - August 2011



Week	Nothing	D0-D4	D1-D4	D2-D4	D3-D4	D4
April 26, 2011	0.00	100.00	100.00	94.97	70.42	17.16

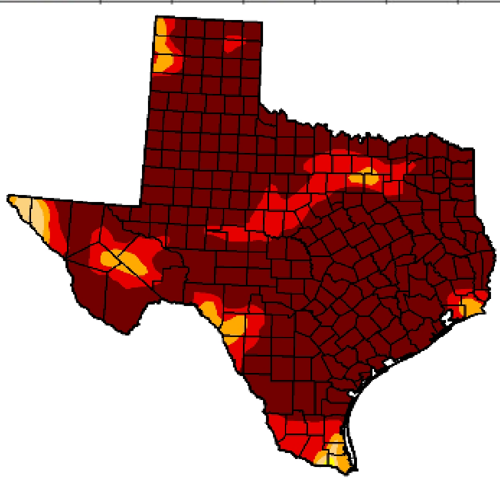
Week	Nothing	D0-D4	D1-D4	D2-D4	D3-D4	D4
May 31, 2011	2.25	97.75	96.07	91.89	81.09	50.65





Week	Nothing	D0-D4	D1-D4	D2-D4	D3-D4	D4
June 28, 2011	2.68	97.32	95.71	94.52	90.62	72.32

Week	Nothing	D0-D4	D1-D4	D2-D4	D3-D4	D4
July 26, 2011	0.00	100.00	99.85	96.88	91.65	75.23



Week	Nothing	D0-D4	D1-D4	D2-D4	D3-D4	D4
August 30, 2011	0.00	100.00	99.92	99.01	95.04	81.08

TexasET Network & Website

The TexasET Network is a collaboration of 32 weather stations across the state used to calculate daily reference evapotranspiration, primarily for irrigation scheduling purposes. Daily ETo is calculated using the Standardized Penman-Monteith Equation which requires hourly weather readings of temperature, relative humidity (used to derive dew point temperature), solar radiation and wind speed. In addition to being able to view daily "real-time" ETo, the network makes available historical monthly averages of ETo data for 19 cities in Texas. These values are often used in water budgeting for irrigation and based on the number of years of record available for each city. Years of record for each city discussed in this paper are shown in Table 1.

Table 1. Historical Years of Record Used to Calculate Historic Monthly Averages on the TexasET Network Website

	Brownsville	**San Antonio**	**Lubbock**	**Dallas**	**Houston**
Years of Data	79	54	89	26	31

ANALYSIS AND DISCUSSION

Five cities on the TexasET Network were chosen based on their location, size and/or requirement for seasonal irrigation. These cities include Brownsville, San Antonio, Lubbock, Dallas and Houston, Texas. Monthly total ETo was calculated for each city from 2008 to 2011 for the months for April through August as well as the 4 year average. The monthly ETo data per year, monthly average for the 4 year period and the historical monthly average for the years of record are shown in Tables 2-6.

Table 2. April Comparison of Total ETo Data

	Brownsville	**San Antonio**	**Lubbock**	**Dallas**	**Houston**
2008	6.04	5.39	6.87	5.55	3.67
2009	5.88	5.53	6.68	6.29	3.68
2010	3.35	5.44	5.69	6.23	3.63
2011	6.33	7.83	8.03	7.16	4.55
4 Year Average	5.39	6.05	6.82	6.31	3.88
Historical Average	5.17	5.47	5.53	5.14	5.01
2011 Increase or Decrease from Historic Value	22%	43%	45%	38%	-10%

Table 3. May Comparison of Total ETo Data					
	Brownsville	**San Antonio**	**Lubbock**	**Dallas**	**Houston**
2008	6.77	6.97	7.79	7.38	4.71
2009	6.52	6.18	6.90	5.79	4.81
2010	3.81	6.95	7.42	7.21	4.91
2011	6.82	8.59	9.42	6.91	5.39
4 Year Average	5.93	7.17	7.88	6.82	4.96
Historical Average	6.03	6.47	6.93	6.21	6.11
2011 Increase or Decrease from Historic Value	10%	33%	36%	11%	-12%

Table 4. June Comparison of Total ETo Data					
	Brownsville	**San Antonio**	**Lubbock**	**Dallas**	**Houston**
2008	7.78	7.82	9.37	8.31	5.23
2009	8.75	8.23	7.69	6.04	6.01
2010	6.83	7.23	8.16	8.50	4.95
2011	7.08	10.1	11.31	10.14	6.11
4 Year Average	7.61	5.82	9.13	8.25	5.58
Historical Average	6.68	6.97	7.73	7.06	6.57
2011 Increase or Decrease from Historic Value	6%	45%	46%	44%	-7%

Table 5. July Comparison of Total ETo Data					
	Brownsville	**San Antonio**	**Lubbock**	**Dallas**	**Houston**
2008	6.09	6.80	7.09	10.81	5.46
2009	10.74	10.09	7.45	9.07	5.65
2010	6.44	7.23	6.13	7.94	4.50
2011	7.42	10.79	8.80	10.47	5.63
4 Year Average	7.67	8.73	7.34	9.42	5.31
Historical Average	6.68	7.31	7.31	7.40	6.52
2011 Increase or Decrease from Historic Value	11%	48%	20%	41%	-14%

Table 6. August Comparison of Total ETo Data					
	Brownsville	**San Antonio**	**Lubbock**	**Dallas**	**Houston**
2008	6.52	5.81	5.47	7.62	4.15
2009	8.85	9.57	7.09	9.00	4.80
2010	7.06	8.45	6.55	9.49	5.25
2011	7.34	9.89	7.66	10.48	5.79
4 Year Average	7.69	8.43	6.69	9.15	5.00
Historical Average	6.65	6.99	7.20	7.25	6.08
2011 Increase or Decrease from Historic Value	10%	41%	6%	46%	-5%

The percent increase (or decrease) in ETo during 2011 was calculated by dividing the measured total ETo for each month by the historical average monthly ETo for each city. This referred to as the “percent change” was graphed to show monthly increases (or decreases) in ETo compared to historical conditions (See Figure 2).

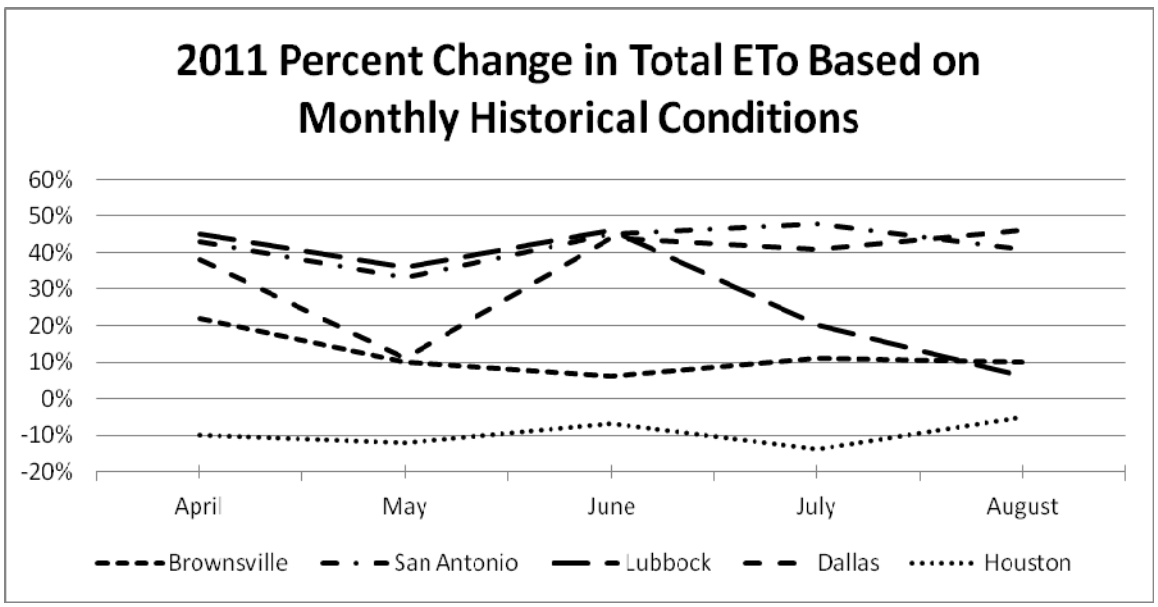


Figure 2.

SUMMARY AND CONCLUSIONS

Basic analysis of the ETo data obtained from the TexasET Network showed that ETo did increase dramatically across most of the state in 2011. Of the five cities evaluated:

- Four cities consistently showed an increase in ETo ranging from 6% to 48% from April to August,
- One of the evaluated cities consistently showed a lower ETo than the historical average, decreasing from -5% to -14%,
- June showed the greatest change in ETo with 3 cities having a percent change greater than 44%.

During the drought, the greatest change in ETo appeared the further north the city is located in the state and the further west, with the least amount of change in monthly ETo occurring along the coastal areas of the state. Further statistical analysis is needed to determine what climatic factors resulted in the significant increase in total ETo during the drought of 2011.

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SEARCHING FOR PREDICTIVE CLIMATE SIGNALS FOR RIVER FLOWS IN THE LOWER COLORADO RIVER BASIN OF TEXAS

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ABSTRACT

The Highland Lakes are operated by the Lower Colorado River Authority (LCRA) in Texas to provide water supply to municipal, industrial, agricultural users and environmental flows for the river and Matagorda Bay. The Highland Lakes also provide for hydroelectric generation and recreation.

The catchment area is in the Texas Hill Country, a region classified as the Edwards Plateau. Subject to extended droughts interrupted by intense rainfall, the region has the nickname of Flash Flood Alley. Precipitation in the region is understood to be influenced by oceanic conditions in the Pacific, Atlantic, and Gulf of Mexico. While the behavior of these global climate patterns is climatologically understood, finding strong skill in prediction of streamflows has been challenging.

Identifying concurrent teleconnections, and to a lesser extend lagging indicators, is a critical first step for finding potential for predictors. Research efforts have often focused on predicting rainfall or climatic indexes. However, surface water managers need to relate predictions to streamflows. Climate indices can also be useful if they are hindcasted, enabling for relationships to the streamflow record to be established.

Persistence is one of the strongest predictive indicators in the region, primarily through the winter season. Persistence is useful in short term predictions because it directly relates to streamflows and indirectly is influenced by teleconnection patterns. Therefore explicitly considering teleconnection patterns adds less incremental short term skill but potential benefit for longer term prediction. Use of persistence and ENSO forecasts are currently being used in water supply forecasts at the LCRA.

INTRODUCTION

The Lower Colorado River Authority (LCRA) is a conservation and reclamation district created by the Texas Legislature in 1934. LCRA supplies electricity for Central Texas, manages water supplies and floods in the lower Colorado River basin, provides public parks, and supports community and economic development. LCRA manages water supplies for cities, farmers and industries along a 600-mile stretch of the Texas Colorado River between San Saba and the Texas Gulf Coast. The LCRA water supply includes a

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combination of interruptible water for agricultural uses and firm water supply for municipal and industrial uses

LCRA operates six dams on the lower Colorado River in Central Texas: Buchanan, Inks, Wirtz, Starcke, Mansfield and Tom Miller. These dams form the six Highland Lakes - Buchanan, Inks, LBJ, Marble Falls, Travis and Austin as shown schematically in Figure 1. Two of these reservoirs, lakes Buchanan and Travis, are the only water supply reservoirs and only Lake Travis has flood control storage. The total combined storage in the Highland Lakes two water storage reservoirs, lakes Buchanan and Travis is approximately 2,010,000 acre-feet of water when at full conservation storage. LCRA regulates water discharges to manage floods, and releases water for sale to municipal, agricultural and industrial users. Installed hydropower generation at these reservoirs provides approximately 295 MW of electrical generation capacity.

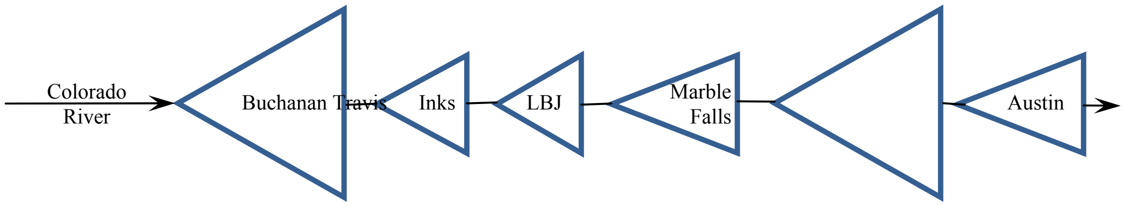

Figure 1. The Highland Lakes Chain of the Colorado River in Texas

Long lead time prediction of streamflows in the Colorado River basin could provide many opportunities for better resource planning and management including water supply, physical facilities, flood management, hydropower generation and scheduling, and environmental provisions. While general long lead time meteorological predictions such as drier than normal or wetter than normal are useful and improving, these do not lend themselves to directly quantifiable forecasts of streamflows or evaporation that can be readily used by surface water supply managers. Even the relationships between rainfall, if it could be accurately predicted, and streamflow, which is a reasonably well understood physical process, have significant variability. For the catchment of the Highland Lakes, statistical regression of the monthly of streamflows, precipitation only partially explains the variations in streamflows. This is likely due to the spatial and temporal variation of rainfall as well as issues such as surface and groundwater interactions and soil moisture conditions which are less easily quantified. Piechota & Dacup (1996) found that while strong relationships between the lagging indices of Southern Oceanic Index (SOI) and Palmer Drought Severity Index (PDSI) could be found, the same was not true for SOI and streamflows. Unfortunately, streamflows are necessary for surface water resource managers in evaluating supply.

There are many contributing factors to the difficulty in long lead time streamflow prediction in central Texas. First the lack of snow pack precludes one of the most helpful predictions available to our counterparts in the Southwest, Pacific-Northwest, and Atlantic Northeast states. Additionally weather patterns are influenced by Pacific generated fronts, Arctic influences, Atlantic influences, Gulf of Mexico influences, tropical disturbances, and even the influences from Canadian cold fronts can have a profound effect. Theses stalled fronts can sometimes be the source for large rain storms such as the Memorial Day Flood of 1981.

Other complications are influences from the north and southward displacement of the Hadley Cell over the southern US. If the cell is displaced further to the north or to the south, it could lead to more convection in Central Texas thus producing more precipitation. Researchers and water managers alike have employed a variety of methods to relate these climatic indicators to streamflow ranging from simple statistical relationships, advanced multivariate methods, and even hydrodynamic modeling.

> The term "teleconnection pattern" refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that spans vast geographical areas. Teleconnection patterns are also referred to as preferred modes of low-frequency (or long time scale) variability. Although these patterns typically last for several weeks to several months, they can sometimes be prominent for several consecutive years, thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. (source: National Weather Service, Climate Prediction Center)

Of the thirteen prominent teleconnection patterns, several have been investigated for use as long lead indicators of hydrology in the area. These include Pacific Decadal Oscillation (PDO), Northern Atlantic Oscillation (NAO), El Niño/Southern Oscillation (ENSO), and Atlantic Multidecadal Oscillation (AMO). Of these indicators, the ENSO is perhaps the best understood and the best quantified indicator for the streamflows in the lower Colorado River basin. ENSO is measured by several indicators including the Sothern Oscillation Index (SOI), the Oceanic Niño Index (ONI), and the Multivariate ENSO Index (MEI). Both ONI and MEI have been computed for long historical periods lending them to be easily correlated with the gaged surface water record.

EL NIÑO/SOUTHERN OSCILLATION EFFECTS ON CENTRAL TEXAS WEATHER

The meteorological influences of the ENSO cycle on Texas weather are rather well understood. In the negative phase, often referred to as La Niña, easterly trade winds increase in strength across equatorial Pacific, causing colder than normal waters to spread west from the coast of South America to near the International Date Line. A "cold tongue" of water develops across central and eastern equatorial regions, leaving a zone of warmer than normal water across across the western Pacific and Indian Ocean. The warmer than normal waters fuel the development of thunderstorms across the western Pacific. Rising air currents associated with the area of thunderstorms tend to sink across the central and eastern parts of the equatorial Pacific, creating a closed area of circulation. The sinking air causes the development of a broad high pressure area across the eastern half of the Pacific. As the Pacific circulation strengthens, the area of high pressure across the eastern Pacific expands to the north. Eventually, the area of high pressure gains enough strength to cause the Polar Jet Stream to shift from southern

California to the Pacific Northwest and western Canada. As the storm track shifts to the north in connection with the Jet Stream, drier than normal weather conditions develop across the southern US, including Texas. This drier than normal pattern often leads to the development of drought. The influence of La Niña can be seen in Figure 2.

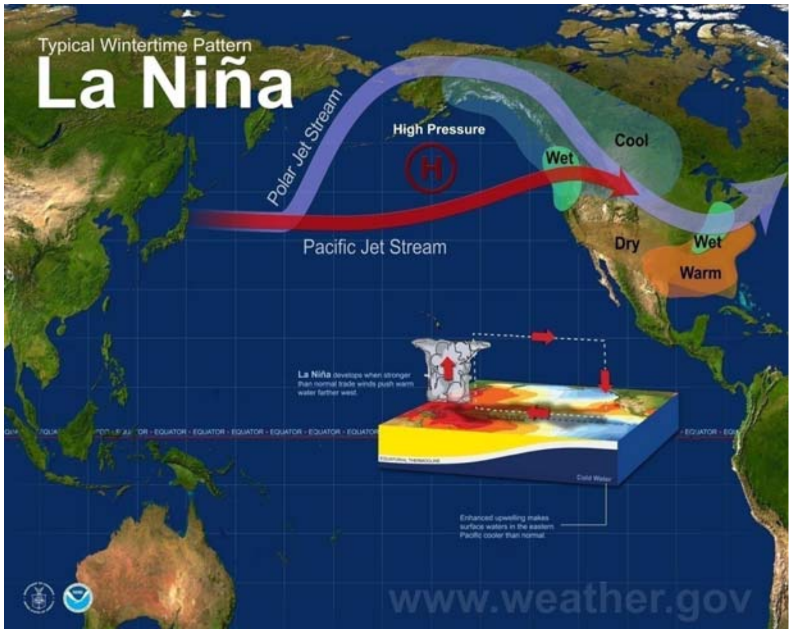

Figure 2. Typical Wintertime La Niña Pattern

The National Climatic Data Center has compiled a set of charts based on the historical record showing the anomalous influence of El Niño and La Niña on precipitation across the US by month. These charts, shown in Figures 3 and 4, also show the departures and percent frequency of occurrence. In the Central Texas region during November to January influence is a 60 to 70% increased frequency of 10 to 70 mm less precipitation as show in Figure 3. The effect is only slightly weaker during the December to February period shown in Figure 4.

In the positive phase of ENSO, often referred to as El Niño, the easterly trade winds diminish and are replaced by westerly trades. These westerly winds pull the very warm waters residing across the western Pacific all the way east to the coast of South America. Eventually a tongue of warmer than normal water develops across the central and eastern equatorial Pacific. These warm waters fuel the development thunderstorms across the central and eastern Pacific, leading to rising air currents, creating a broad area of low pressure. As the broad area of low pressure strengthens, circulation around the low helps focus the storm track across the southern US.

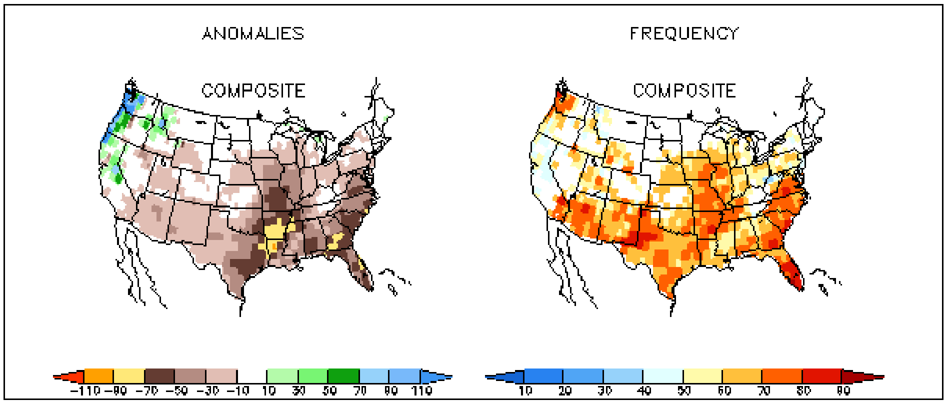

Figure 3. U.S. Precipitation Departures (mm)
Frequency of Occurrence (%) for La Niña during Nov.-Jan.

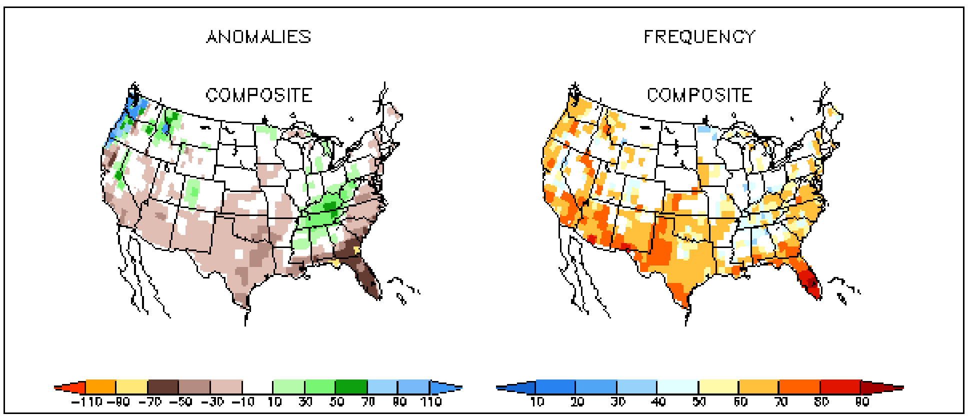

Figure 4. U.S. Precipitation Departures (mm)
and Frequency of Occurrence (%) for La Niña during Dec- Feb.

The flow of moisture off the Pacific Ocean, in combination with a flow of moisture off the Gulf of Mexico, creates frequent periods of storms, resulting in above normal rainfall. A recent summary of ENSO model predications is show in Figure 5 which shows a period of relatively long range consensus among predictions. While the horizon of consensus of the ENSO predictions is often longer than streamflow persistence, it is still short relative to multi-year water supply system operations.

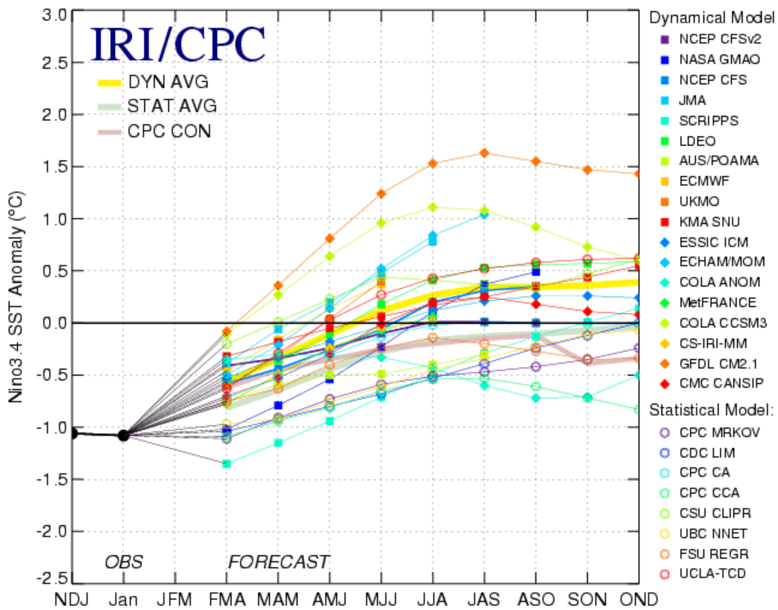

Figure 5. ENSO Model Predictions for February 2012

SUMMARY OF PREDICTION STUDIES INVOLVING CENTRAL TEXAS

O'Connell (2002) focused on the longer term indicators of ENSO and the NAO, noting that the PDO cycle was too long to be of much management use as a indicator. She examined correlation coefficients between streamflow in lower Colorado River basin and the indicators for the period of 1940 to 1999 on an annual time step. While she found good correlation between concurrent data, leading indicators showed only minor correlations. She found the indicators to be capable of improving annual forecasts by 11-13% over persistence alone, and an optimal linear combination used SOI and NAO to gain a 49% improvement" but noted "skill inflation may have occurred, as forecasts were not tested on an independent data set." Interestingly, she identified the strong month to month persistence that often exits in the streamflow data sets apart from teleconnections. However that was not directly useful for the modeling approach. Furthermore, at the time, she suggested that without strong lead correlations, the indictors were not useful as predictors. However, now a decade later, we have easy access to good dynamic and statistical prediction models, at least for ENSO, which can make concurrent relationships useful for several months in the future even where leading predictions by indicators may not be established.

Hydrological Persistence: The characteristic of hydrologic conditions to remain in wet or dry cycles. Interactions between global climate process and the hydrological cycle can result in rainfall and stream flow data clustering into wetter and drier conditions.

In hindsight, the prediction skill may have been improved through classification of ENSO into El Niño, Neutral, or La Niña rather than a continuous variable, since the strength of the condition seems to have less impact than the condition alone. Similarly the streamflows and the ENSO indexes are highly correlated so the lack of additional information from the ENSO index may be due to the fact that the ENSO signal is already largely incorporated into the antecedent conditions. LCRA now uses both the persistence and the ENSO forecasts for aiding prediction (Anderson and Walker, 2010) of streamflows and subsequently lake contents.

Dr. James Tolan (2006) also investigated ENSO impacts in Texas but with a focus on salinity along the Texas Gulf Coast. However, this is still of interest since, in some areas, salinity can be related to streamflow with potentially less error than precipitation (Anderson, Wedig, and Tyagi, 2009). Dr. Tolan analyzed the period of 1982 to 2004 using seasonally standardized salinity. He found major cross correlations between both ENSO and PDO while also finding minor correlations with NAO and yearly season cycles. Dr. Tolan also identified five frequencies associated with the variation in salinity that correspond to ENSO but the period of salinity record is short in relation to the patterns.

Slade and Chow (2011) focused their study on the Texas Hill Country using the period of 1950 to 2009. While they looked at precipitation, flood flows, and streamflows, our interest here is streamflows. Their results confirmed the meteorological understanding of ENSO influences. They found for each gage in the region that the mean streamflow during El Niño periods exceeds the mean streamflow during La Niña periods. While this exceedence was only slight in the San Saba River, Llano River, and Johnson Creek; the exceedence was substantial at the more southerly gages of such as the Pedernales, Guadalupe, and Blanco Rivers. The focus of their work was diagnostic rather than predictive, therefore they only looked at concurrent conditions or lagging indicators rather than leading indicators such as was done by O'Connell.

NOAA Operational Definitions for El Niño and La Niña Episodes

- El Niño: characterized by a positive ONI greater than or equal to +0.5°C.
- La Niña: characterized by a negative ONI less than or equal to -0.5°C.

CPC considers El Niño or La Niña conditions to occur when the monthly Niño3.4 OISST departures meet or exceed +/- 0.5°C along with consistent atmospheric features. These anomalies must also be forecasted to persist for three consecutive months.

Quan et. al. (2011) looked at the ability to reproduce the historical standard precipitation index (SPI) for the period of 1982 to 2002 using dynamic atmospheric climate simulations across the United States. While SPI is not easily related to streamflows, the results of the research echo findings of other research in the central Texas area. They note that inherent drought persistence alone provides considerable seasonal skill. Furthermore, they note that dynamic sea surface temperature (SST) models do improve predictive skill, and that ENSO is believed to be the preponderance of the skill source in the Southern US.

Wei, W. and Watkins (2011) evaluated ENSO, PDO, and NAO specifically related to flows in the Lower Colorado River. They conducted an ordinal polytomous logistic regression approach to forecasting streamflows. Of all the indicators they evaluated, they found that only hydrologic persistence and ENSO or PDO provided any skill over mean seasonal streamflow patterns.

ANALYSIS USING NON-PARAMETRIC-METHODS

As has been shown in the literature, persistence and ENSO are skillful in predicting streamflows in central Texas for up to several months. While other indicators may be shown to be good predictors of climate indices, further research is needed to quantify the impacts of PDO and NAO to central Texas streamflows. Past research suggests that additional indicators may only provide marginal additional prediction skill but continued advances in the understanding and simulation of teleconnection patterns may prove otherwise.

The gaged record of the Highland Lakes for the period of 1940 to 2011 was analyzed and computed for the month to month persistence of streamflows for conditions of El Niño, La Niña, neutral, or unspecified. The computed persistence is the basis for transitional probabilities used to constrain chaining Marcov forecasts. Monthly streamflows are grouped into lower quartile, inner quartile range, and upper quartile bins for dry, medium, and wet conditions respectively. The three antecedent classes, three transitional classes, and 12 months a year result in 108 potential combinations of prior distributions for describing transitional probabilities. Furthermore, considering the four ENSO classifications results in 424 combinations.

These prior distributions capture both the persistence and ENSO impacts as the supported by the literature. An example of the transitional probabilities for the condition of unspecified ENSO is shown in Table 1.

Table 1. Transitional Probability of Persistent Quartiles for Unspecified ENSO Condition

Last Mon	This Mon	**Persist Dry**	Dry to Medium	Medium to Wet	Medium to Dry	**Persist Medium**	Medium to Wet	Wet to Dry	Wet to Medium	**Persist to Wet**
12 1		**76.47%**	23.53%	0.00%	14.29%	**65.71%**	20.00%	0.00%	42.11%	**57.89%**
1 2		**77.78%**	22.22%	0.00%	11.11%	**75.00%**	13.89%	0.00%	27.78%	**72.22%**
2 3		**61.11%**	27.78%	11.11%	19.44%	**72.22%**	8.33%	0.00%	27.78%	**72.22%**
3 4		**72.22%**	27.78%	0.00%	13.89%	**61.11%**	25.00%	0.00%	50.00%	**50.00%**
4 5		**33.33%**	55.56%	11.11%	33.33%	**52.78%**	13.89%	0.00%	38.89%	**61.11%**
5 6		**38.89%**	50.00%	11.11%	27.78%	**44.44%**	27.78%	5.56%	61.11%	**33.33%**
6 7		**66.67%**	27.78%	5.56%	11.11%	**69.44%**	19.44%	11.1%	33.33%	**55.56%**
7 8		**50.00%**	38.89%	11.11%	25.00%	**55.56%**	19.44%	0.00%	50.00%	**50.00%**
8 9		**55.56%**	27.78%	16.67%	19.44%	**66.67%**	13.89%	5.56%	38.89%	**55.56%**
9 1	0	**61.11%**	11.11%	27.78%	16.67%	**58.33%**	25.00%	5.56%	66.67%	**27.78%**
10 11		**72.22%**	27.78%	0.00%	11.11%	**66.67%**	22.22%	0.00%	38.89%	**61.11%**
11 12		**77.78%**	22.22%	0.00%	11.11%	**72.22%**	16.67%	0.00%	33.33%	**66.67%**

The observed transitional probabilities in Table 1 have been compared to random probabilities. The transitional probabilities which cannot be rejected at a 95% confidence as randomly occurring are shaded in the table. Only six of the 36 persistent states appear to be random. These are predominantly during the April to May and May to June transitions. This is reasonable since this is the period of spring rainfall also known as the 'barrier period'. The majority of the transition probabilities reflect statistically significant month to month persistence. Said another way, the odds of switching out of a condition, or even more so from wet to dry or dry to wet conditions, rarely follow random probabilities.

Table 2 presents the observed transition likelihoods under La Niña conditions. The average increase in the likelihood of remaining in dry conditions or transitioning to the next dryer condition than under the unspecified condition is 12%.

Table 2. Transitional Probability of Persistent Quartiles for La Niña Condition

Last Mon	This Mon	Persist Dry	Dry to Medium	Medium to Wet	Medium to Dry	Persist Medium	Medium to Wet	Wet to Dry	Wet to Medium	Persist Wet
12	1	72.73%	27.27%	0.00%	0.00%	77.78%	22.22%	0.00%	50.00%	50.00%
1	2	88.89%	11.11%	0.00%	16.67%	75.00%	8.33%	0.00%	0.00%	100.0%
2	3	77.78%	11.11%	11.11%	37.50%	50.00%	12.50%	0.00%	20.00%	80.00%
3	4	90.00%	10.00%	0.00%	16.67%	66.67%	16.67%	0.00%	60.00%	40.00%
4	5	37.50%	37.50%	25.00%	55.56%	44.44%	0.00%	0.00%	33.33%	66.67%
5	6	57.14%	42.86%	0.00%	25.00%	75.00%	0.00%	33.33%	33.33%	33.33%
6	7	60.00%	20.00%	20.00%	14.29%	42.86%	42.86%	0.00%	0.00%	100.0%
7	8	0.00%	66.67%	33.33%	37.50%	37.50%	25.00%	0.00%	50.00%	50.00%
8	9	100.0%	0.00%	0.00%	40.00%	50.00%	10.00%	0.00%	33.33%	66.67%
9	10	71.43%	14.29%	14.29%	18.18%	63.64%	18.18%	0.00%	50.00%	50.00%
10	11	85.71%	14.29%	0.00%	23.08%	69.23%	7.69%	0.00%	28.57%	71.43%
11	12	88.89%	11.11%	0.00%	18.18%	72.73%	9.09%	0.00%	50.00%	50.00%

In Table 3 we see the likelihood under El Niño conditions. During El Niño conditions, we observe an average increase of 28% likelihood of transitioning out of dry conditions to moderate conditions throughout the year and an annual average of 7% increase in the likelihood of staying either medium or wet.

Table 3. Transitional Probability of Persistent Quartiles for El Niño Condition

Last Mon	This Mon	Persist Dry	Dry to Medium	Medium to Wet	Medium to Dry	Persist Medium	Medium to Wet	Wet to Dry	Wet to Medium	Persist Wet
12	1	100.0%	0.00%	0.00%	15.38%	69.23%	15.38%	0.00%	75.00%	25.00%
1	2	25.00%	75.00%	0.00%	8.33%	75.00%	16.67%	0.00%	14.29%	85.71%
2	3	nd	nd	nd	9.09%	81.82%	9.09%	0.00%	14.29%	85.71%
3	4	0.00%	100.0.%	0.00%	11.11%	44.44%	44.44%	0.00%	50.00%	50.00%
4	5	0.00%	100.0.%	0.00%	16.67%	83.33%	0.00%	0.00%	66.67%	33.33%
5	6	50.00%	50.00%	0.00%	18.18%	45.45%	36.36%	0.00%	25.00%	75.00%
6	7	66.67%	33.33%	0.00%	0.00%	87.50%	12.50%	0.00%	42.86%	57.14%
7	8	50.00%	50.00%	0.00%	14.29%	71.43%	14.29%	0.00%	33.33%	66.67%
8	9	50.00%	50.00%	0.00%	22.22%	66.67%	11.11%	0.00%	50.00%	50.00%
9	10	75.00%	25.00%	0.00%	8.33%	50.00%	41.67%	0.00%	50.00%	50.00%
10	11	50.00%	50.00%	0.00%	11.11%	44.44%	44.44%	0.00%	28.57%	71.43%
11	12	75.00%	25.00%	0.00%	11.11%	88.89%	0.00%	0.00%	20.00%	80.00%

* nd = no data

As the data is binned into further classifications, the number of observations gets small. As seen in Table 3, there is one state of transition that has not yet been observed in the gaged record. This posses a technical issue in using non-parametric methods if more indicator variables were to be incorporated.

CONCLUSIONS

Researchers have investigated climate predictive indicators in Texas and specifically in the lower Colorado River catchment for many years. Efforts focused on predicting streamflow, rainfall or climatic indexes. Surface water managers need to relate predictions to streamflows either by dynamical or statistical methods for use in supply management. Qualitative or classification indicators can be useful if they are also hindcasted so they can be related to the streamflow record with a statistical methods and the prediction uncertainty can be characterized. Month to month persistence is recognized as one of the most skillful indicators, primarily through the winter season. Persistence is useful in short term predictions because it directly relates to streamflows and indirectly is influenced by teleconnection patterns. Therefore explicitly including teleconnection patterns adds less incremental short term skill but still offers potential benefit for longer term prediction.

> A **hindcast** is a way of testing a mathematical model. Known or closely estimated inputs for past events are entered into the model to see how well the output matches the known results. Hindcasting is also known as backtesting.
>
> An example of hindcasting would be entering climate forcings (events that force change) into a climate model. If the hindcast accurately showed weather events that are known to have occurred, the model would be considered successful. - Wikipeda

Even though most research has focused on concurrent indicators rather than leading indicators, concurrent relationships may still be useful in prediction as global circulation models provide better and further outlooks into future climate. Use of lagging climate indicators may also help identify driving climate indicators but pose more challenges for prediction of streamflow. Use of persistence and, concurrent ENSO relationships, and ENSO forecasts are currently being used in water supply forecasting at the LCRA. Additional skill may be achieved through future research with AMO interactions with ENSO forecasts (Nielsen-Gammon, 2011) as long as the historical record is reasonably long for use in providing confidence in the streamflow relationships and understanding of the prediction uncertainty. Finally, even when additional indicators prove to be statistically significant they still need to provide substantively better projections over existing indicators to be of benefit to water managers.

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WATER REUSE IN DROUGHTS AND DESERTS

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ABSTRACT

Water reuse, particularly reuse of treated wastewater, has been in discussion for a number of decades as municipalities and farmers have viewed a valuable resource flowing back into the river after going through two or three levels of treatment. Resistance in reuse comes from a cultural idea of not reusing treated wastewater for drinking or growing edible crops, probably from the fear that it will transmit diseases from the water or contaminate foods grown with the water. There is also an objection to having animals grown for food drink the treated wastewater, fearing that they may catch diseases, or transmit diseases, from the water.

This paper will present the experience of the Buckeye Water Conservation and Drainage District ("BWCDD" or the "District") in using treated wastewater from the largest wastewater treatment plant ("WWTP") in Phoenix, AZ. Approximately 65% of the water supply for the District comes from the WWTP. Agricultural crops using the water are restricted to fiber and animal feed. The area supports a large health dairy industry with nearly 20 operations and is one of the premier areas for growing fine Pima cotton. We will not argue for using WWTP water for food crops but rather address how water reuse from this source may substitute for scarce supplies of stored, ground or pumped water. BWCDD also uses its water resource for generation of electricity at a drop on one of its weirs, providing further reuse of its canals and water.

INTRODUCTION

The BWCDD has a rich history, one filled with pioneering and an enduring spirit.

When a site was identified in 1885, the founders of the original Buckeye Canal Company went about constructing a canal and diversion, and the first water was turned into the canal in 1887. Having foresight, the founders listed the canal's purposes to be "agricultural, milling or mechanical enterprises."

Although ahead of their time in foresight, the owners of the canal were ill prepared to wrestle with the turbulent Gila River. The canal changed hands five times from 1887 to 1907, finally ending up in the hands of the Buckeye Irrigation Company ("BIC"). The BIC was made up of a group of local farmers with a personal stake in the success of the canal.

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During the late 1910's, the farmers and operators of the canal saw signs of waterlogging on land next to the river because of excess irrigation on the higher ground. In 1922, the Buckeye Water Conservation and Drainage District was formed to finance a new dam and attempt to correct the waterlogging problem. The BWCDD overlaid the lands already being irrigated by the BIC.

While the BWCDD was formed to dewater the lands along the river, it has assisted in the operation of the Buckeye Canal since 1922. In 2000, the District assumed overall responsibility for the canal and acquired title to the canal and the South Extension in 2008. It continues to dewater the District lands with 10 drain wells, pumping approximately 30,000 AC-FT annually.

BWCDD is an irrigation district with the power of drainage, and under Arizona statutes, it is a municipal corporation of the State of Arizona. The District occupies approximately 22,000 acres, with 16,000 acres irrigated. The canal stretches through the towns of Avondale, Goodyear and Buckeye, all located within Maricopa County. The Main Canal is 23.5 miles in length and the South Extension is another 7.5 miles in length.

FIRST STEPS TOWARD SUSTAINABILITY

With the growth of the Phoenix Valley in the early 1920's, a decline of stream flow from the Gila River was seen at the District's headgates even when the river was flowing abundantly. BIC was able to offset the losses with wells, but the water came at a much higher cost.

Looking for a stable and cost effective option, in 1971 the District contracted with the City of Phoenix to take treated wastewater effluent from the 91st Avenue wastewater treatment plant. This was in recognition of the need to conserve water, in all of its conditions, to meet the growing demands of an expanding population. Knowing that effluent reuse would require a shift in types of crops grown but would also provide a more reliable water supply, the District began receiving water from the WWTP later that year. Originally the District began receiving 30,000 acre-feet per year. As the population of the City expanded, as did the WWTP, the amount of water received from this source was expanded to 65,000 acre-feet per year. While effluent provides a significant volume for the District, they still incur large electrical bills for the water pumped to meet seasonal demands.

THE WATER POWER NEXUS

The recovery of energy from moving water has existed throughout modern history. From water wheels for grinding grain to powering the machines of the early industrial revolution, converting moving water to useful power was also the natural selection of energy to provide the first large scale generation of electricity. Consequently, electricity became the most effective way to move water to population centers, treat and condition the water for human consumption, and then to collect, move and treat waste water after it had been used. This interdependence of water to make power-whether for hydro generation or water used in the cooling towers at gas, coal or nuclear power generation plants, and the use of power for the delivery and conditioning of water and wastewater- has only become more intense as the population has expanded to the suburbs and regulation of both water and wastewater has become stricter. Stricter regulations have required more power to treat both fresh water and wastewater, and expanding areas have required more power to move water further and further.

The importance of turning water into power can be illustrated by the fact that 75% of the renewable energy for electricity production in the United States in 2005 came from hydroelectric resources. The International Energy Agency estimates that 19% of the world's electricity was generated by hydropower in 2005. Norway gets 95% of its electricity from hydropower.

As to the use of power for water, California estimates that 20% of the power consumed in the state was used to supply, distribute, collect and treat water. California is on the high end of electricity use for water because of the movement of water from the North part of the state to the Los Angeles basin. Within the United States, EPRI estimates that just under 4.0% of electricity is used in water and wastewater treatment applications.

As attention has shifted to renewable resources, not only to offset the ultimate decline in fossil fuels, but also to mitigate the potential impacts of climate change, the potential for a renewal in hydropower development is being given a lot of study. The U. S. Department of Energy has estimated that there is a potential to double the capacity for hydropower generation in the United States, primarily through previously undeveloped low head hydropower resources. This could add from 30,000 to 70,000 MW of capacity to the approximate 70,000 MW of existing capacity, but without building another high dam.

SUSTAINABILITY II – GENERATE OUR OWN POWER

In 1889, a survey by Major Edward H. Wilton recorded a drop of 40 feet over three sections of the canal. Was this the prescience to think of generating electricity? In the 1980's the canal was surveyed again, looking for potential sites to harness the power of the flowing water. However, a viable technology was not found based on the survey results.

In early 2007, management at the BWCDD again began to consider ways to use its moving water to generate electricity. Management was concerned with the potential for escalating rates of purchased power, but just as important, they were aware of a wasted resource, the energy in the drops at the check structures in the canal system. Irrigation or water supply canals are designed with a certain slope to let the water flow down to its destination. If the water flows too fast it can damage the walls of the canal. Periodically, check structures and drops may be installed to dissipate the excess energy or to accommodate changes in the level of the terrain. Check structures also maintain a pool level in the canal so that water can flow by gravitation into laterals that irrigate the crops.

In the exploration of alternative methods of generating power we came across the Schneider Linear Hydroengine ("SLH"). The promise of this technology was that it could generate electricity efficiently and economically in low head environments that had not been economically practical with standard turbine machinery.

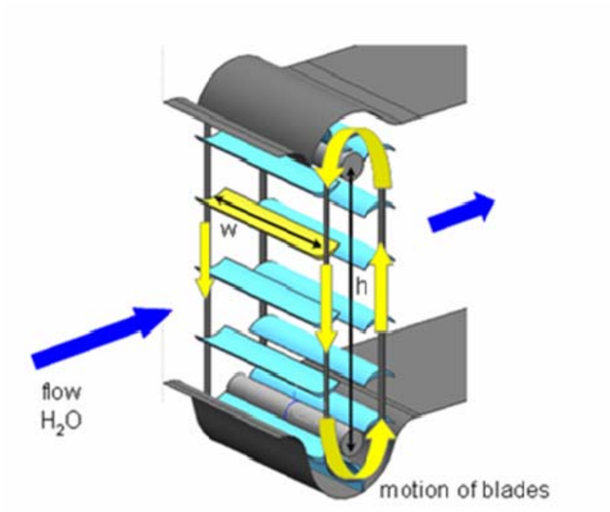

Figure 1. Foil configuration of the SLH

The SLH had been installed in an irrigation canal during a previous energy crisis, as well as having been operated in a remote mountain setting and stream diversions. The developer of the technology, Natel Energy, Inc., was looking for a site with which to demonstrate its latest evolution of design and materials of construction.

After touring different site possibilities, Natel and the District selected a site on the South Extension that could meet the needs of both parities. The District then solicited other critical partners to make the installation of the SLH a joint effort that could enhance the business prospects of each. The benefit of this effort was that the District could end up with a facility that contributed to its sustainability by lowering purchase power costs and decreasing carbon emissions. In the partnership, the District would provide the site and modifications of the drop structure to allow installation of the SLH. Natel would provide the engine, along with the inlet gates, penstock, draft tube, generator and electronic controls. The District's civil engineering firm, Stantec, Inc., contributed design of the civil structure and powerhouse. A fourth partner, K. R. Saline and Associates contributed the siting and permitting with the Federal Energy Regulatory Commission ("FERC"). At the end of the demonstration period, BWCDD will own the generation facility, but more importantly can assess its viability to install additional units at as many as five more sites within the District's canals.

THE SOUTH EXTENSION SITE

BWCDD and Natel selected a site on the South Extension canal that would accommodate a nominal 20 kW capacity machine. The site is very accessible, has a moderately consistent flow and was across the road from a connection to an electrical distribution line. The site had a 9.5 foot drop while the SLH is rated at 20 kW at 15 feet of drop and 23 ft^3/s flow.

Figure 2. South Extension canal drop

The desirable feature of access near the intersection of two roads also requires that the installation have good security. To enclose the SLH, Stantec selected a pre-cast vault to house the SLH. A by-pass chute was installed alongside the SLH to carry water when the engine was being serviced or to carry excess water flow. To improve the operating characteristics of the SLH, the District was able to add about two feet of drop by lowering the down stream pool as the site was being prepared for installation. The installation of the power house took place during the District's normal dry period in November of 2009, after receiving the exemption from permitting from FERC in September of 2009. A photograph of the installed power house is shown in Figure 3.

Figure 3. Installed Powerhouse – South Extension

To calculate the revenue potential 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.

The flow duration curve shown in Figure 4 provides the basis for a pro forma operating statement for the demonstration unit at BWCDD. The engine capacity design is for 20 kW of capacity at 15 feet head and flow of 23 ft^3/s. The actual drop is 9.7 feet and average flow is 11 ft^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.

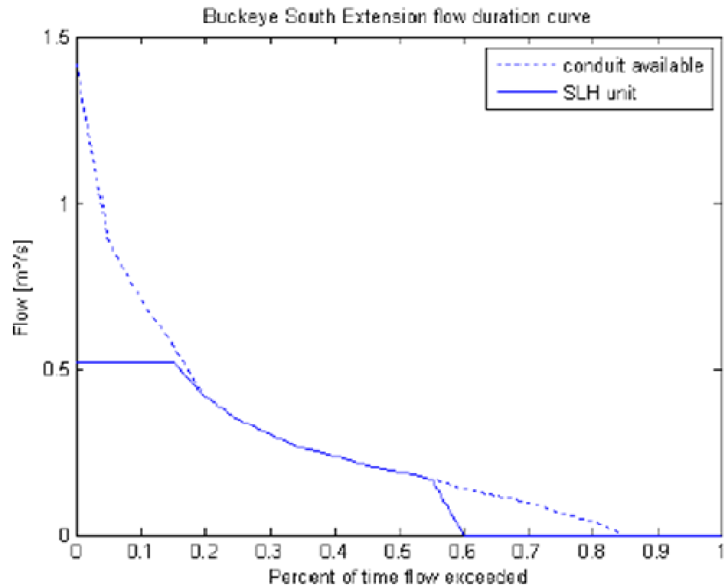

Figure 4. Flow Duration Curve for South Extension Site

By lowering the down stream pool of the South Extension site the District has improved the economic potential of the SLH, so that the capacity utilization will probably be closer to 35%.

The 20 kW SLH installation at the South Extension would not be profitable as measured by standard monetary inputs and outputs. However, because of the contributions of all of the partners, the system will provide a payback to the District. For the other partners there are the prospects that this installation will lead to commercial installations from 100 kW to 1,000 kW in size. Natel has calculated the system cost for SLH sized ranging from 20 kW to the 1,000 kW size. To scale from the small size to the large, Natel can increase the throat dimension by making it taller or wider, or both. The engine components are made larger accordingly.

Economic considerations for SLH sizes above 20 kW are more favorable. A scaling study has provided system cost estimates for all sizes up to 1,000 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 capacity utilization experienced. Natel’s estimated of lifecycle cost per kWh based on a 20 year life, 8% cost of capital and $0.02 O&M is shown in Figure 5.

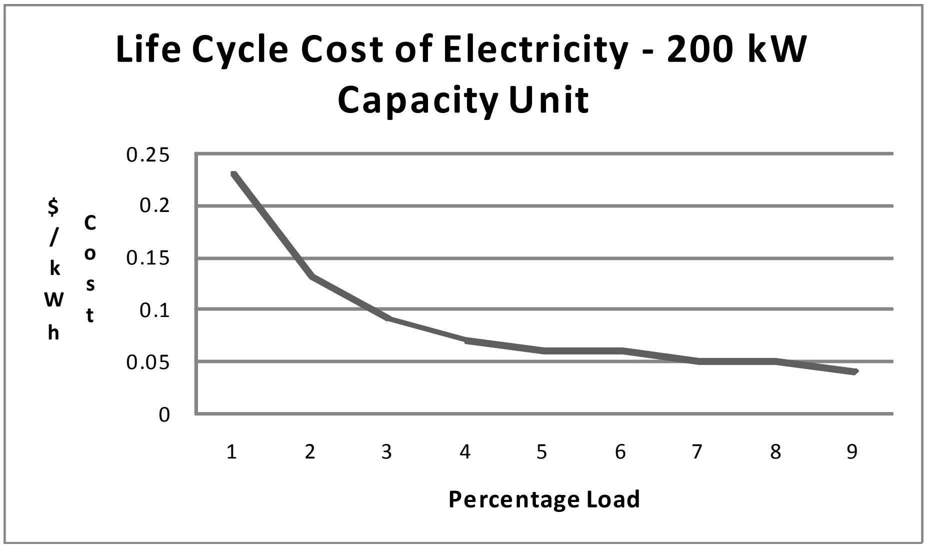

Figure 5. Life cycle cost of Electricity SLH 100

The monetary 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 30%, 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 ITC and 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 becomes 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 six cents ($0.02 - $0.06) per kWh in RECs over the coming years.

REGULATORY CONSIDERATIONS

At the beginning of the project, neither the District nor the developer was aware of the cost and timing of the regulatory requirements, even for a small demonstration unit such as the 20 kW machine to be installed at the South Extension. Although FERC does not require a permit for this type of project, the application for an exemption is still substantial. By requesting an exemption from licensing, there is no requirement for an environmental impact statement. However, an environmental assessment is required and notification to all interested parties, such as state regulatory and environmental agencies. FERC sends notices to the federal agencies to be sure that they have no objections. Under normal circumstances, the cost and time requirement for an application for an exemption to install a project like the South Extension would make it prohibitive. Now that we understand the information and timing requirements, dealing with permits for larger projects will be more efficient and much more cost effective.

FUTURE ENERGY RECOVERY OPPORTUNITIES

As we prepare for the future at BWCDD, our concerns are the escalation of purchased power prices, the availability of water supplies to maintain the irrigated acres of farm production and the societal concerns of global warming and carbon dioxide reduction. We keep close tabs on inputs and outputs to measure the effectiveness of how we operate the District. Table 1 below shows that we reduced power consumption from 2007 to 2008, with the total cost of power declining slightly. However, the cost per kWh of electricity increased by 7% year over year. To improve its sustainability factor, the district has as an objective to cut purchased power by 20% over the next decade. We believe that can be achieved by additional generation capability at current check drop structures and drops to be constructed.

Table 1. BWCDD Water and Power Statistics 2007 – 2008

	2007	2008
Electricity consumed - kWh	13,297,942	12,077,763
Peak Demand during year - kW	2,991	3,046
Total Power Cost	$ 535,829	$ 520,794
Water Demand – Irrigation in acre-feet	128,000	129,000
Water Supply – acre-feet		
WWTP/Gila River diversion	67,400	82,500
SRP Tail Water	35,800	31,400
Pumped Ground Water	79,200	74,200
Drain Water Pumped	31,120	26,950

After operating the SLH unit at South Extension for several months, the District will begin the assessment of future opportunities for electricity generation. We have identified at least five sites that may prove economic and help to reduce purchased power substantially. Two of the sites currently have check structures that can provide quick implementation. The other three are planned structures as we augment supply and direction of water flows. The sites that we have identified are:

Goodyear	WWTP inflow
Johnson	Road
Gate	67 Drop – Bottom end
Suzy	Dean Drain
Watson	Drain

These sites offer the potential to add up to 235 kW of capacity. Water flows and drops indicate approximately 50% nameplate capacity utilization. Additional generation from these sites could provide approximately 20% of the District's 2008 electricity consumption.

CONCLUSION

The decision by the BWCDD to work in partnership with Natel to install a small demonstration unit of a unique generation technology will have direct benefit to the District in several ways. By demonstrating the technology we can provide an avenue for our use, as well as providing commercial proof of the technology for adaptation in the United States and around the world. Importantly, we will tap an unused resource of our irrigation system as a method of promoting sustainability. By offsetting electricity purchases from the grid we will reduce our operating cost and hedge against some of our future electricity costs. And, by generating electricity with a renewable resource we will reduce our carbon footprint significantly.

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HOME CONSUMER PERCEPTIONS ABOUT LANDSCAPE WATER CONSERVATION AND RELATIONSHIPS WITH HISTORICAL USAGE

Whitney Milberger-Laird[1]

ABSTRACT

Water is considered to be one of the most limited and precious resources on Earth. Due to this scarcity, water conservation has become essential in order to preserve water resources. Landscape plant material brings quality to urban and suburban lifestyles and increases value to home properties. Yet it has been shown that an excess amount of water is often applied to landscapes when the plant material does not in fact need the supplemental irrigation.

A researcher based survey, the Landscape Water Conservation Survey, was sent to 799 single family homes in College Station, TX. Data collection occurred from November 2005 through August 2006 with a 27% return. The survey asked the recipients 14 questions on water use and home consumers' perceptions. Historical landscape water usage was compiled from 2000-2002 which included actual water use, taxable value of the residence, heated area, and the water meter identification number for these selected households supplied by the City of College Station Water Utilities.

The survey indicates a strong disconnect between the amount of irrigation landscape plant materials need and the quantity of water that is actually applied. Surveyed home consumer perceptions demonstrate excessive amounts of irrigation were normally applied to landscape plant material when no irrigation was needed due to rainfall. Many respondents to the Landscape Water Management Survey indicated that they believed to have efficient irrigation practices in place when in actuality they do not. Educational resources are needed to teach the public on the amounts of irrigation landscape plant materials actually need, how to apply measured home irrigation practices, the principles of water conservation, and meeting the water requirements of varied landscape plant material. If these could be established and implemented, there would be a higher rate of conserving water and providing plant material with the sufficient amount of irrigation required.

INTRODUCTION

Water is critical to our existence. Preserving potable water supplies continues to be a major issue in Texas, the nation, and world. Of all the earth's water, only 1% is actually available for human consumption. Population expansion and demand will increasingly tax a finite water supply (Water Right, 2003). The Texas Water Development Board states in the State Water Plan <u>Water for Texas 2012</u> that water demand in Texas is projected to increase by 22 %, from about 18 million acre-feet per

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year in 2010 to a demand of about 22 million acre-feet per year in 2060 (TWDB 2012).

Water is considered to be one of the most limited and precious resources, yet in landscape management an excess amount of water is often applied with no regard to actual plant needs (Qian & Engelke, 1999) even in xeriscape landscape designs (Carrow, 2006). Although water use increases dramatically during summer months due to outdoor use for landscape irrigation (Kjelgren, Rupp, & Kilgren, 2000), little to no published information is available about the relationship of actual water used for landscape irrigation and amount of water needed to sustain landscape plant health and quality.

Although municipal water utilities recognize that home consumer outdoor water consumption increases dramatically during summer, these agencies do not know whether the increased water used is necessary to sustain healthy landscapes (Nations, personal communications, 2004). Thus, information that would elucidate the relationship between seasonal home consumer water consumption and estimates of water required to sustain healthy landscapes would aid municipal water agencies in targeting water conservation efforts.

Excess water consumption may be perpetuated by home consumers' misconceptions that plants need to be watered every other day. For proper irrigation management, established trees and shrubs should be irrigated after they show signs of stress (Knox, et al., 1991). Approaches to curb outdoor water consumption most often include conservation education, landscape design, landscape plant selection, specific or limited watering days, block or tiered pricing, and in severe situations, restrictions on outdoor water use. Michelsen, McGuckin, and Stumph (1999) determined that non-price conservation programs incorporating multiple approaches can significantly reduce residential water use. Yet, they also determined that such programs would only reduce demand by 1.1 to 4.0%.

Water conservation is both easy and difficult because of the lack of a quantitative relationship between the performance of landscape plants and the inputs of water. The diversity in landscape species within individual landscapes and their water use characteristics make whole mixed landscape irrigation management recommendations difficult (Kjelgren, Rupp, & Kilgren, 2000). Incorporating native vegetation, "low water use plants," and even desert adapted species in the landscape may not always result in water conservation. Minimal research exists to document the impact of landscape design type and plant choice on water conservation; studies have indicated that these two factors alone do not result in reduced landscape water use.

Peterson, McDowell, and Martin (1999) provided compelling evidence that landscape water use was influenced more by irrigation management by Arizona municipal water consumers than by landscape design and plant type. They suggested factors such as plant density, total landscape foliage cover, plant size, and growth rate were greater determinants of water applied to landscapes than the presence or absence of low water requiring or desert adapted plant materials. The San Antonio Water System (SAWS) conducted a pilot study to determine the effects of converting existing residential landscapes to water conserving landscape designs that included native and low water use plants from a recommended plant list on monthly household water consumption (Finch, personal communication, 2003). According to Finch, the results of the SAWS study indicated that about 25% of the households that participated had lower monthly irrigation because of the change in landscape design and plant type. About 75% of the participants had equal or greater monthly irrigation after changing to the landscape design and plant materials recommended by SAWS. The failure of 75% of the participants to achieve water savings after converting to a “water efficient landscape” was associated with poor irrigation management practices.

Many water consumers lack the ability to manage landscape irrigation efficiently and therefore changing to landscape designs that include native, drought resistant, or even plants adapted to desert environments will not guarantee municipal water savings. Evapotranspiration (ET) is the measured amount of total water a plant needs. Potential evapotranspiration of a grass reference crop (ETo) is the technical term that observes the potential ET assuming the crop is under well watered conditions and deep soils (Texas ET Network, 2010). Instruments from research plots have the ability to measure actual evapotranspiration (ETa) on a given day. Knowledge of actual water lost via ETo from landscapes is required to irrigate landscapes efficiently.

Havlak (2004) measured ETa in an irrigated Weslaco, Texas landscape comprised of turf and woody ornamentals using ETo as a reference. Havlak determined a landscape coefficient that could be used for irrigation scheduling. The landscape irrigation coefficient estimated from daily ratios of ETa:ETo was 0.65 for the period of February to September 2003.

Even when using a water efficient landscape, poor irrigation practices resulted in increased outdoor water consumption (Havlak, 2004). Good zoning, irrigation system design, and hardware reduce soil and landscape variability (Carrow, 2006). The real water management issue is finding out how consumers can learn to exploit water conservation strategies while sustaining economic viability (Carrow, 2006). As the need to conserve water has increased, so has water usage. City ordinances have started changing landscape water rights, making decisions as to qualifying turfgrass species that are allowed for planting, and in some cases outright banning the use of turf altogether (Water Right, 2003). In San Antonio, SAWS offered a rebate program to home consumers who applied xeriscape landscape design principles that included plants with a low water requirement Yet, research has shown that xeriscape landscape designs can actually use more water annually (Martin, 2001, 2003). These programs being created may be appropriate for conserving water in locations where water is seasonally scarce.

Turfgrass is an exceptional landscape resource because of the enrichment it brings to life. Without turfgrass and trees to cool the soil surface, urban heat islands may develop (Jones et al., 1990; Oke, 1982). Turfgrass entraps organic pollutants, protects the loss of soil from erosion, enhances degradation of pesticides, reduces climatic temperature, provides fire protection by making a noncombustible green zone, gives a self-repairing living groundcover, aesthetic beauty, and most importantly to homeowners, enhances property and home values (Beard & Green, 1994). Research studies have confirmed that water conservation may be achieved to a point prior to the permanent decline in turfgrass quality. This implies the potential for a decrease in environmental contribution, recreational usage, and the economic value of the property (Carrow, 2006).

According to Hughey and others (2004), "While environmental and conservation-type surveys have been undertaken over the last decade (Heylen Research Centre, 1993; Petersen, et. al, 1997; Massey University, 2001) there have been few ongoing surveys of perceptions of the environment". The Landscape Water Management Survey attempts to grasp home consumer's perceptions on irrigation efficiency and methods. The word "landscape" may be first perceived as a picture idea (Titchener, 1899). When gazing at a landscape and turning eyes to different parts, it cannot be said how many perceptions take in the scenery or where each perception ends (Spencer, 1872). Therefore, perception may be difficult to quantify.

Consumer awareness must be addressed for meaningful water conservation. Changing home consumers' landscape irrigation practices depends on a successful water conservation education program and a shift in their traditional practices (Aston & Whitney, 1993). A strong need exists to evaluate home consumers' perceptions about landscape water conservation and to use these perceptions to develop educational programs that effectively alter home consumers' water conservation management practices.

LANDSCAPE WATER MANAGEMENT SURVEY

The Landscape Water Management Survey was presented to 799 participants. From these 799, 26 surveys were thrown out due to flawed addresses. There was an outcome of 211 responses for a 27% return. These 799 single family homes were selected because valid water meter data on actual home water usage was available for the households. The survey included 14 questions on perceptions of their own landscape water use. The outcome of these questions provided insight into the perceptions of efficiency, information sources, environmental factors, methods, quality, and knowledge of landscape water use.

The survey initially wanted to establish how the respondent perceived their landscape. If the rating was low, then many of the questions would have little to no relevancy to the respondent. It was imperative to know how much the participant actually valued their landscape. When participants were asked how important an attractive, healthy landscape is to their quality of life, 182 (89.6%) of the respondents indicated above average importance and 21 (10.4%) indicated below average importance. On a scale of 1 (not important) to 6 (very important), there was a (M=4.76, SD=1.1). These data indicated that almost 90% of the respondents do have strong positive feelings about their landscape. The responses illustrate that the participants are interested in maintaining a vigorous landscape and probably desire to do so long-term.

The 30 year annual rainfall in College Station averages around 102cm, yet periods of droughts do occur (NOAA, 2010). The perceived value of the respondents landscape to their quality of life suggested why the respondent had strong feelings about the significance of landscape irrigation. When the participant was asked how important landscape irrigation is to them, 172 (84.7%) of respondents indicated that irrigation was above average in importance and 31 (15.2%) rated irrigation below average in importance. The response had a (*M*=4.66, *SD*=1.1). These results indicated that the majority of participants perceive that irrigation is important for an attractive, healthy landscape.

When asked if the participant considered their water utility bill to be abnormally high during the summer months, 98(46.9%) reported no, 77(36.8%) said yes, and 34 (16.3%) were undecided. Since more than 30% of the respondents considered their water utility bill to be high during the summer months, an opportunity exists to demonstrate how that bill can be lowered through conservation irrigation.

When asked if the survey participant knew how many liters of water he/she used each month, only 17 (8.1%) of the respondents answered yes. One hundred ninety-two (91.9%) of the respondents did not know how many liters of water they used each month.

To better understand how to get people to start conserving water, it was pertinent to find out what will make consumers turn off their irrigation systems or irrigate less. The survey asked how important would an incentive be to operate the respondent's system more efficiently and use less water for landscape irrigation (Table 1).

Table 1. Importance of incentives to operate irrigation systems more efficiently to use less water for landscape irrigation.

	Responses by Category					
Incentive Type	1 2 3		4 5		6	
Lower utility bill due to reduced use	5	10	11	14	45	110
Better landscape quality	6	11	13	30	49	80
Healthier landscape plants	4	9	21	28	48	80
Rebates for efficient irrigation systems	17	11	15	24	42 76	
Conserving water is enough incentive	3	12	29	32	53	67
Other 7 3 1 2	5					18

Note. Scale: 1 = Not Important…6 = Very Important.

Rating the responses below average (1-3) and above average (4-6), 169 of the respondents would like to have a lower utility bill due to reduced irrigation use. Sixty-seven of the respondents replied conserving water is enough of an incentive, but 192 of the respondents replied they don't even know how much they use. Demonstrating the relationship between efficient irrigation, better landscape quality, plant health, and a lower utility bill would result in a positive impact on water conservation. If they have better information on how to determine water usage then home consumers could, in actuality, conserve water, have a healthier and high quality landscape, and have a lower utility bill. In contrast to other cities, there have never been water restrictions in

College Station, TX resulting in less incentive to become educated for water conservation (J. Nations, personal communication, May 4, 2004). This implies water consumers in this population have never actually been required to irrigate less.

Irrigation water requirements of landscape plants differ for most landscape plants (Parsons et al., 1997). In order to develop effective landscape water management strategies it is important to understand home consumer perceptions about the amount of irrigation needed by various plant types. Participants were asked how much water they perceived lawns, trees, shrubs, flowers, ground covers, potted plants, and vegetables needed to maintain plant health and quality (Table 2).

Table 2. Perceived amount of water needed by different landscape plant types.

	Frequency by Plant Type				
Plant Type	1 2 3 4 5				6
Potted Plants	33 35 45 37 22 18				
Lawns	5 22 57 60 48 16				
Vegetables 26	16	46	35	36	15
Flowers 18	24	54	55	41	7
Trees	32 50 55 41 16				5
Shrubs 24	48	73	40	12	3
Groundcovers	44 47 64 26			5	3

Note. Scale: 1 = A Little…6 = A Lot.

Most of the respondents perceived that their lawn and flowers need about the same amount of water to maintain plant health and quality. Most of the respondents answered that trees, shrubs, ground covers, potted plants, and vegetables require the same amount of water. The survey did not attempt to establish the respondents' knowledge of the maturity of their landscape or experience with the plant types used. Yet, the responses illustrate that home consumers perceive that diverse plant types have similar water needs. Their irrigation practices therefore would likely not be different for high and low water use plants.

Knowing how the respondents perceive their irrigation practices was important for comparing their perceptions to their knowledge of the amount of water they used for irrigation each month. Whether they perceived their irrigation practices as efficient or inefficient was also of interest for comparison with the historical amount of water they used for irrigation (Table 3).

Table 3. Respondent perceptions of the efficiency of their irrigation practices.

Efficiency Rating	*f*	%
Somewhat efficient	141	67.8
Very efficient	38	18.3
Inefficient	23	11.1
No opinion	6	2.9

One hundred seventy-nine of the respondents rated their irrigation practices somewhat to very efficient. The other 29 either had no opinion or rated their practices inefficient. The respondents who rated their irrigation practices inefficient or had no opinion are suggested to have a negative perception about their irrigation practices. Respondents who rated their irrigation practices somewhat efficient are labeled as having a neutral perception, and the very efficient as having a positive perception about their irrigation practices. There was not a significant correlation (0.0251) between perceived landscape irrigation efficiency and perceptions about plant water requirement. Those that had a negative perception about plant water requirements did not consider themselves to irrigate any more efficiently or inefficiently relative to other respondents.

A series of questions pertained to irrigation practices, water requirements, and specific plant needs. Knowing the amount of irrigations per week provides a perspective on typical landscape irrigation frequencies. Participant's responses indicated irrigation from 0 to 7 times each week (Table 4).

Table 4. Number of weekly landscape irrigations reported by respondents.

Irrigations/Week	*f*	%
3 76		37.6
2 64		31.7
1 37		18.3
4 9		4.5
0 8		4.0
5 5		2.5
6 2		1.0
7 1		0.5

The questions in the Landscape Water Management Survey were not adjusted for seasonal influences. However, according to Pittenger and Gooding (1971), "*A person behaves in terms of what is real to him or her and what is related to his or her self at the moment of action*" (Knowles, Holton, and Swanson, 2005). This implies the respondent was answering upon the time the survey was received. The survey was first sent to home owners on November 7, 2005. Most respondents (140) irrigated two to three times per week whereas, 17 of respondents irrigated from 4 to 7 times each week with a (*M*=2.34, *SD*=1.1). These responses indicated that 17 (8.5%) of the respondents irrigate their landscape more than 3 times each week and 185 (91.6%) of respondents irrigate their landscape 3 times each week or less.

Matching irrigation water application amounts with water consumed by plants is critical to efficient irrigation and water conservation. The survey indicated a disconnect between the perceived irrigation efficiency of respondents and their knowledge of water applied to their landscape. Landscape water conservation strategies should include scrutiny about how to determine actual amount of irrigation water used. It is difficult to understand how so few participants knew how many liters of water they use each month yet such a high frequency believe they have somewhat to very efficient irrigation practices.

It is good to know of the source or action that determines when one will irrigate landscapes. This could be a way of educating people on water conservation and irrigation water needed by various plant species.

Table 5. Factors affecting respondent decisions about when to irrigate landscapes.

	Percent of Responses by Response Category					
	1	23	4 5 6			
Frequency of rain	4	4	5 16 54			122
Temperature	3	4 10 35 77 74				
Condition of my plants	3 12 19 36 61 73					
Other	36 1 1 3 5					10
My landscaper decides	155	9	13 4 7 7			
Irrigation installer decides	162	13	11	3	4	3
When my neighbor waters	162	13	14	2	3	2

Note. Scale: 1 = Not at All…6 = Always.

A high number of respondents indicated that when their neighbor waters, irrigation installer decides, or their landscaper decides has no affect on when they irrigate. Most of the respondents do have neighbors and this question is understandable. Many people don't want to admit they depend on neighbors. Yet, it is difficult to understand why irrigation installers and landscapers do not affect when the respondents irrigate. It might be that the respondent does not have contact with either but if they do, the irrigation installer and landscaper could be the educator on teaching the respondent the amount of water each plant type needs. The irrigation installer could then teach a respondent with an automatic sprinkler which zones need more or less water. These data would indicate an opportunity for landscape and irrigation professionals to have a greater influence on landscape irrigation water conservation. The majority of the respondents reported that the condition of their plants, the frequency of rain, and the temperature always affect when they irrigate. This is good to know because if there is an abundance of rainfall or perhaps a freeze they would likely reduce landscape irrigation for a period.

Irrigation methods help one understand why people might be overwatering or under-watering. If there is a drought, then one would have to be more attentive to irrigating their landscape if they don't have an automatic programmed system (Table 6).

Table 6. Frequency and percentage of types of methods used to irrigate landscapes.

Irrigation Methods	*f*	%
In-ground automatic system	150	44.1
Hand held hose	90	26.5
Hose and sprinkler	64	18.8
In-ground manual system	35	10.3
I do not irrigate my landscape	1	0.3

The participants were able to answer more than once to the method of irrigation used. Almost half of the respondents use a hand held hose in conjunction with another method. Two hundred and forty of the respondents irrigate their landscape with an in- ground system. One hundred fifty have automatic systems. If the respondent is not aware of plant water needs and the amount of water that is being applied to the plant material, they may be wasting water, money, and potentially reducing plant health and landscape quality. In-ground systems are an easy way to irrigate but there were no efforts to ascertain if these systems were monitored by the respondent.

The survey asked if in the respondent's opinion, is there enough information available about how to irrigate Texas landscapes efficiently. Eighty-seven reported no, 55 reported yes, and 55 were undecided. The participants were asked what sources they use to get more information about irrigating landscapes more efficiently. The participants could answer multiple times to this survey question about sources of information that they use. It is important to remind the reader that this is College Station, TX specific. Within this sample of the population, 35 of the respondents depend on the radio for information about irrigation. Many respondents do not depend on a garden club or their neighbor for information about irrigating. However, 108 of the respondents reported that the internet is the source they would use to obtain information about irrigating landscapes more efficiently. Internet based information appears to be the most efficient way to deliver information to this population. There is an opportunity here for the water utilities office and the retail garden centers to become more pro-active in reaching out to home consumers with landscape water management information.

Historical Outdoor Water Usage

The trend in outdoor water usage among non-respondents and respondents in 2000 was similar. In 2000, the increase in outdoor water usage began in April with peak usage in July, August, and September. Peak outdoor water usage in July, August, and September corresponded to relatively low rainfall during those months. Outdoor water usage began to decrease into late-summer and fall. However, more than 30cm of precipitation were recorded in October and November and although there was a trend of a steady decrease in outdoor potable usage, no landscape irrigation would have been required during October and November based on previous estimates by White et al. (2004).

In 2001, outdoor water usage started to increase in the middle of March. Zero precipitation was recorded in March and April and only 0.10 cm of precipitation were recorded in May and June. A marked decrease in outdoor water use occurred between August and September although landscape water requirement for the months of September, October, November, and December were estimated to be near zero (White et al., 2004) The outdoor water consumed by non- respondents and respondents was similar in 2001.

In 2002, there was a typical increase in outdoor water usage in April through June. A substantial reduction in average outdoor water usage in July coincided with over 21cm of precipitation during that month. However, average outdoor usage peaked in August for a second time in 2002 even though substantial precipitation was recorded. Precipitation amounts during July, August, September, and October should have precluded the need for supplemental landscape irrigation to maintain plant health and quality (White et al., 2004) yet substantial amounts of irrigation were applied to landscapes based on average outdoor water usage during July through October.

In the Landscape Water Management Survey, 112 of the respondents reported that the frequency of rain always affects their irrigation practices. This is not reflected in the historical outdoor water usage reported for respondents during 2000 and 2001.

Historical Outdoor Water Usage in Relation to Participant Responses
A gradual increase in the average water used and estimated water used out-of- doors was observed from May through August across all 3 years (Table 7). Although total water used increased about 16,300 liters from May through August, water used out- of-doors increased over 12,500 liters during the same period. During June through September, out of door water use accounted for more than 62% of the total water consumed. During August, almost 56% of all water consumed was used out-of-doors.
The mean outdoor water usage during 2000, 2001, and 2002 was compared to the participants rating of their irrigation efficiency.

Table 7. Average total water usage, water used out-of-doors, and percentage of total water used out-of-doors by survey respondents in College Station, Texas from January through December for 2000, 2001, and 2002.

Average	total water used	Average water used out-of-doors	Percentage of total water used out-of-doors
Month -------------	-----1,000's of liters------------		
1 27.3		0 0	
2 25.4		0 0	
3 26.9		0 0	
4 34.1		0 0	
5 59.1		7.4	12
6	63.1 11.5 18		
7	72.1 20.5 28		
8	91.8 39.7 43		
9	69.5 17.7 25		
10 48.4		0	0
11 31.8		0	0
12 26.5		0	0

In May, respondents who rated their practices to be very efficient used slightly more than an average of 45,300 liters out-of-doors per month and the respondents who gave no opinion on their efficiency rating were the second lowest water users averaging 46,400 liters. The highest water users in May averaging over 59,200 liters of water use out-of-doors were the respondents who rated their irrigation practices to be inefficient.
In June, respondents who rated their practices to be inefficient were the highest out-of-door water users and consumed more than 63,100 liters of water out-of-doors on average.

The respondents who believed they had very efficient irrigation practices used on average 50,000 liters of water out-of-doors in June. In July, the respondents who had no opinion about their outdoor water usage efficiency used on average 1,240 liters less than the month before. Also, the respondents who rated their irrigation practices inefficient used more than 3,800 liters less in July than in June. The respondents who rated their systems somewhat efficient to very efficient had almost 20% greater outdoor water usage in July compared with June.

August was the peak month for water use out-of-doors with the respondents who rated their irrigation practices somewhat efficient using more than 87,300 liters of water. Those that rated their irrigation practices as inefficient used slightly more than 80,000 liters. The respondents who gave no opinion on their irrigation efficiency used more than 79,900 liters of water out-of-doors in September. The respondents who rated their practices to be very efficient used slightly over 56,000 liters of water in September.

In October all of the outdoor water usage decreased compared to usage in August and September. The respondents who rated their practices inefficient used about 17,000 liters less in October than September. The respondents who rated their practices to be somewhat efficient used slightly approximate to 19,200 liters less and the respondents who rated their practices to be very efficient used over 20,800 liters less in October than in September.

In May and June the participants that perceived their irrigation practices as inefficient used 11% more water out-of-doors on average than those participants that perceived their irrigation practices as somewhat efficient. Yet in July and August, the participants that perceived their irrigation practices as somewhat efficient used 12% more water on average than those participants that perceived their irrigation practices as inefficient. In September and October the participants that perceived their irrigation practices to be inefficient used 18% more water than the participants who perceived their irrigation practices to be very efficient. During 2000, 2001, and 2002 respondents did not use water for landscape irrigation in amounts consistent with their perceived irrigation efficiency. Respondents used the most water out-of-doors in August for 2000, 2001, and 2002. There was not a significant correlation between historical outdoor water usage in August and perceptions about plant water requirement (Table 8).

In addition, there was not a significant correlation (-0.0603) between respondents' perceptions of irrigation efficiency and perceptions of plant water needs. Those that had a positive perception about plant water requirements did not necessarily irrigate less than other respondents.

SUMMARY AND CONCLUSIONS

The Texas Water Development Board stated that if there is a drought in 2050, approximately 43% of municipal water utilities will not have sufficient water available to meet demand (TWDB, 2005). Researchers have already suggested that changing home consumers' landscape irrigation practices depends on a successful water conservation education program and a shift in their traditional practices (Aston & Whitney, 1993). The Landscape Water Management Survey and the outdoor historical water usage data presented in this paper support this conclusion.

I was very satisfied with the 27% response from The Landscape Water Management Survey. It is clear that about 90% of the respondents do believe that having a healthy and attractive landscape does add to their quality of life. This indicates that it is important to reach out to the community and help it understand the importance of measured irrigation practices. The Survey did not address participants to consider seasons of the year. Therefore, the number of times the respondent irrigated their landscape might change throughout the year. The results of the study indicated that more than 91% of the respondents irrigate their landscapes 0-3 times per week in the summer months when there is minimal rainfall. The results also indicated that respondents irrigated 0-3 times per week even when there is substantial rainfall.

When the respondent was asked how much water is needed by plant type, flowers and turfgrass were rated the highest. Annual flowers generally do require more water than other landscape plant types and if already established and rainfall is adequate, turfgrasses may only require moderate supplemental irrigation. The responses show that diverse plants were perceived to have the same watering requirements. The Survey also showed that there were 130 neutral perceptions and 31 negative perceptions among participants about the plant water requirements. There is a demonstrated need to educate the public about seasonal plant water needs. Again, there have never been water restrictions in College Station, TX that imposed incentive to become educated for water conservation (J. Nations, personal communication, May 4, 2004).

The Survey showed that about 86% of the respondents rated their irrigation practices to be somewhat to very efficient. Yet only 8.5% of the respondents reported knowing how many liters of water they used out-of-doors each month. This indicates that most of the home consumers do not know how many liters of irrigation water they use each month. Knowing the volume of irrigation water applied is crucial to estimating the efficiency of an irrigation system. Once one can determine the plant material's water need only then can an irrigation schedule be efficient and the number of liters used per month may be adjusted or understood.

Irrigation installers and landscapers have the opportunity and responsibility to teach home consumers how and when to irrigate landscapes. A very small percentage of the respondents indicated that their irrigation installer or landscaper influence their decision on irrigation schedules. Over 70% of the respondents indicated that they have an in-ground automatic system. There could be a possibility that an automatic irrigation system was installed prior to purchasing the home and the homeowner did not know the installer. Landscapes may have already been established when respondents moved into their homes or respondents might landscape themselves. If the home consumer does have a landscaper, the landscaper also could assist the homeowner as to irrigation requirements. It is very rewarding to know that over 58% of the respondents said that the frequency of rain affected when they would irrigate. This shows awareness to precipitation and a link to home consumers that when it rains, there is no need to irrigate.

Over 40% of the Survey respondents responded that there is not enough information available about how to irrigate Texas landscapes efficiently. The internet was the highest source respondents utilized to get more information about irrigating landscapes more efficiently. This gives experienced individuals in landscape water management, such as the county extension agent, water utilities office, and the retail garden center, an opportunity to educate the public on water conservation and plant water needs. Over half of the respondents indicated that a lower utility bill due to reduced use would encourage them to use less water for landscape irrigation. This reinforces the need for greater educational opportunities for home consumers about water conservation.

The historical outdoor water usage for 2000, 2001, and 2002 all had similar trends in that there was irrigation applied to landscapes when no irrigation was required in particular months. Again, over 58% of the respondents in the Landscape Water Management Survey suggested that the frequency of rain influences their irrigation practices. This is not reflected in the historical outdoor water usage for all three years.

In the month of May, the respondents who rated their systems to be inefficient used the most liters of water out-of-doors. This is a good indicator that the respondent is aware there are problems in their irrigation practices. The same indicator is reflected in the month of June. The highest out-of-doors water users were the respondents who rated their irrigation practices to be inefficient, using again 11,355 more liters of water than respondents who rated their irrigation practices to be very efficient.

Yet in July and August there was a shift in who used the most water out-of- doors. In July, the respondents who rated their irrigation practices as somewhat efficient to very efficient used more water out-of-doors than participants who rated their irrigation practices inefficient or had no opinion. In August, the respondents who rated their irrigation practices as inefficient used 1514 liters less than the respondents who rated their irrigation practices to be very efficient. There is a misperception by the respondents who rated their irrigation practices to be very efficient for the month of August. If one rates a practice to be somewhat to very efficient, less irrigation water would be used.

In September, the respondents who rated their irrigation practices to be very efficient used 22,700 liters less water out-of-doors than the respondents who gave no opinion. This is a similar trend as in May and June. In October, the out-of-doors water usage decreased significantly by all respondents. This response was well received because the month of October usually ends the growing season for most warm season plants.

The data presented from The Landscape Water Management Survey in relationship to the historical outdoor water use gives a clear understanding that there is a misperception between how home consumers view irrigation practices and the actual amount of irrigation is used on landscapes. Based on the results of this research, there is a strong need for educational programs to promote and achieve internet accessible programs and information on water conservation. This method would be the most relevant for this population since 108 respondents said this is their main source of information about irrigating landscapes more efficiently.

According the Knowles, Holton, & Swanson (2005), "Learning occurs as a result of a change in cognitive structures produced by changes in two types of forces: (1) change in the structure of the cognitive field itself or (2) change in the internal needs or motivation of the individual". If educators can help home consumer's start thinking more about irrigation water usage, water as a precious resource, and the need to preserve water, irrigation practices and beliefs may change also. When the price of water on utility bills increases, this will likely cause the motivation to start irrigating properly. However, the need to teach *how* to irrigate properly is indisputable.

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ADVANCING AGRICULTURAL WATER CONSERVATION IN COLORADO

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ABSTRACT

Population growth and climate variability are increasing pressures on limited water resources, and extensive collaboration is needed to develop long-term working solutions to this complex issue. Agriculture consumes an estimated 90 percent of available water resources in the western U.S., and future water needs for an expanding urban population will likely come from agriculture. Therefore, it is increasingly urgent for farmers, water managers, extension agents, and policy-makers to understand agricultural water conservation methodology, technology, and policy to make informed management decisions. Reliable information on the subject is often not readily available to water users, especially outside of the academic and government communities. The USDA-NIFA Northern Plains and Mountains Regional Water Team (NPM) has addressed the need for increased knowledge, understanding and adoption of agricultural water conservation through an innovative web-based project. The Agricultural Water Conservation Clearinghouse (AWCC) (www.agwaterconservation.colostate.edu) seeks to join communities of practice to collaboratively address the complex issues of agricultural water use. The AWCC is designed as a comprehensive resource for the latest news, research, literature and tools related to agricultural water conservation. The focal point of the AWCC is a library that contains references to published materials populated by Extension specialists, research scientists, and educators, providing a refined bibliographic review of agriculture water conservation grey literature. The Library encompass over 3,600 entries of refereed journal articles, books, reports, theses and dissertations, and conference proceedings. The AWCC has been searched by over 21,000 users since it was unveiled in 2008 and participation continues to grow.

INTRODUCTION

Agricultural water conservation is complicated by a number of physical, legal, institutional and economic factors, while the forces applying pressure on agricultural water use are acute. Notable among these pressures are increasing competition for water resources due to population growth and resulting impetus to transfer agricultural water to other uses, while at the same time sustaining or increasing agricultural output.

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Additionally, the need for water for wildlife habitat, recreation, energy production and other uses continue to increase. Today, competition for limited water supplies is a continual theme in the semi-arid and arid West, and it recurs whenever drought persists in the wetter regions of the United States (U.S.).

A number of factors constrain how agricultural producers manage their water supplies including availability, timing, quantity and quality of water, water rights administration, crop needs, precipitation patterns, irrigation equipment performance, labor, production costs and anticipated returns. Agricultural water conservation is a highly complex issue that is often mistakenly simplified in the public discussion and at the policy level. The complexity of agricultural water conservation is further influenced by:

- state laws which limit incentives for agricultural water conservation;
- variability and inconsistency of policies from state to state, despite water resources transcending political boundaries;
- research that has far surpassed application by many irrigators;
- financial barriers and lack of recognizable incentive to irrigators for conservation;
- cumulative basin-scale impacts and the downstream dependency on return flows;
- individual producer debt/equity ratio and risk management strategies;
- limitations imposed by inefficient irrigation equipment and water delivery infrastructure; and
- current approaches to ditch and reservoir system management and administration.

The World Economic Forum predicts that percentage change in demand for water between 2000 and 2030 for industrial and domestic use will crowd out any growth in agricultural water use (WEF 2009). Water demands from urban growth, increases in reservoir evaporation, and increases in crop consumptive use must be accommodated by timely improvements in agricultural water delivery, management practices, and technology (Strzepeck et al. 1999).

Because agriculture accounts for over 70 percent of the water used consumptively in the U.S., the public, some natural resource regulatory agencies, and policy makers have started to place an increasing focus on the notion of agricultural water conservation as a partial solution to existing water shortages or those being forecast as a consequence of climate change predictions, over-appropriate and use of existing water resources, and growing and shifting populations throughout the U.S. Yet, in light of growing emphasis on water conservation, it is estimated that present agricultural water shortages have cost the U.S. agricultural sector $4 billion a year for the past two years (WEF 2009).

Agriculture Water Conservation in Colorado

According to the 2007 USDA Ag Census, slightly less than half (48 percent) of Colorado's three million irrigated acres have been converted to sprinkler or drip systems. In particular, irrigators who rely on deep or declining groundwater already have significant incentive for water conservation. Many Colorado farmers have switched to irrigation systems with enhancements such as drop nozzles, low-pressure delivery systems, irrigation scheduling, soil moisture monitoring, minimum tillage, and other techniques to improve on-farm efficiency and reduce pumping requirements (Barta et al., 2004).

However, in Colorado a relatively complex set of laws, regulations, and customs pertaining to the use and transfer of water rights has evolved over the past 150 years. In particular, this body of law leads to the orderly allocation and administration of water rights when surface flows are inadequate to satisfy demand.

Under Colorado water law, water rights can be changed in the type, place, or timing of use as long as the change does not adversely affect other vested water rights, whether absolute or conditional. Put another way, appropriators are entitled to the continuation of stream conditions at the time of their appropriation—including return flows from upstream water users. The doctrine of prior appropriation recognizes a right of junior appropriators "in the continuation of stream conditions as they existed at the time of their respective appropriations" (*Farmers High Line Canal & Reservoir Co. v. City of Golden*). The "No Harm Rule" provides protection to water right holders from injury when a water right is changed in Water Court (DiNatale et al., 2008).

Increasing the efficiency of irrigation water use under a valid water right does not require a formal change of use proceeding. For example, an agricultural user may increase efficiencies by improving water delivery (e.g., lining ditches, pipelines, or polyacrylamides) or by on-farm applications (e.g., sprinklers, drip systems), yet still maintain the overall decreed use of irrigation on the same lands. Water conserved within a given ditch system may in some cases be used within that ditch system. There are potential legal issues with the irrigation company conserving water and then giving or selling that water permanently outside of the system. Although such activities do not require a change of use proceeding in water court, these types of improvements could have detrimental impacts on other water users to the extent that the change alters return flows and/or increases the consumptive use. With no formal change case involved, legal mechanisms to protect downstream water rights and interstate compacts are limited. If irrigation conservation and efficiency measures are to be promoted on a broad scale, then consideration should be given to the substantial effects this might cause, including reduced water available to water right holders and interstate compacts.

Ensuring the continuation of historical return flow patterns to protect downstream juniors is possibly the largest hurdle to overcome when dealing with agricultural water conservation. To illustrate the complexities involved, the Colorado Water Division II Engineer's Office has recently promulgated rules and regulations for agricultural water users in the Arkansas River Basin to ensure that irrigators converting to higher efficiency systems do not adversely affect return flow patterns and increase consumptive use, thereby affecting the state's ability to meet its compact obligations with Kansas (Colorado Division of Water Resources, 2011). While Colorado water law allows the conversion of irrigation systems to more efficient ones (i.e., flood to sprinkler systems) without a formal change proceeding in the water courts, the promulgation of these rules is a recognition that these actions can have negative effects on return flows and those relying upon them.

In addition to impacting downstream water right holders, implementing agricultural water conservation measures may have other significant effects. For instance, flood irrigation and seepage through earthen ditches and canals provide for significant aquifer recharge. In certain cases, domestic and irrigation wells have been impacted when groundwater recharge from historical irrigation practices was not maintained.

Increased agricultural water conservation could potentially result in a voluntary reduction in the diversion of water to the farm, creating benefits such as improved water quality, allowing water to remain in the streams, and reducing energy costs for pumping, but may not result in water that can be legally transferred to other uses. If water conservation measures can improve water supply availability without causing injury to downstream users or the environment, then the result may be increased water supplies for agriculture and other uses.

When evaluating agricultural water conservation improvements, it is important to distinguish between practices that lead to improved application efficiency and those that lead to reduced consumptive use. Water use efficiency is defined as the ratio of water applied compared to water consumed by crop (i.e., ET). Increasing efficiency is likely to reduce losses from deep percolation and runoff (thereby altering historical return flow patterns), but it may or may not materially affect the amount of water consumed by the plant. Much of the water lost to these inefficiencies will return to the river or groundwater system for use by downstream diverters. For this reason, the administrative practice in Colorado is that water saved due to improved efficiency is not available for additional irrigated lands or other expanded uses.

Salvaged and Saved Water in Colorado

Two concepts related to water conservation have emerged from Colorado case law: salvaged water and saved water.

- Salvaged Water is generally viewed as water that results from reducing nonproductive consumptive use of water, such as by the cutting or removal of phreatophytes.
- Saved Water is generally viewed as water that results from more efficient diversion and application methods.

In 1974, the Colorado Supreme Court in *Southeastern Colo. Water Conservancy Dist. v. Shelton Farms* (1974) ruled that water salvaged by the removal of phreatophytes ("water-loving" plants such as tamarisk and cottonwoods) belongs to the river system and is subject to administration in order of priority. Water salvaged by reducing evaporation or cutting vegetation does not belong to the person responsible for the salvage and cannot result in a new water right, free of the river's call. The Court in *Shelton Farms* stated that while landowners are prohibited from claiming water rights by cutting down phreatophytes, there is a need for the Legislature to address and clarify the issues of saved and salvaged water.

Over the last two decades, there have been attempts in Colorado to create legislation that would provide the right to sell, transfer, and/or reuse water resulting from salvaged, saved, or conserved concepts. An attempt was made to address the issue of "saved" water in 1991 when HB 91-1110 was introduced as a bill allowing the sale, transfer, or reuse of "saved water" as long as it caused no injury to any downstream water right holders. This bill was not successful. Discussions regarding new state legislation on this topic since that time have gained insufficient traction to even result in proposed legislation.

Nonetheless, agricultural water conservation measures have been implemented in a number of specific situations in Colorado. A few examples include:

- The federally funded salinity management program on the West Slope where water conservation measures, improved irrigation, and canal lining were implemented to reduce salinity mobilization due to deep percolation.
- In 2005 and 2006 some San Luis Valley irrigators voluntarily shut off end guns on their center pivots to reduce ground water withdrawals by an estimated 8 percent.
- Some Colorado growers on the High Plains Aquifer where groundwater levels are declining have adopted cropping patterns that include splitting pivot circles acreage of cool season crops such as wheat or lower water use crops such as sunflowers.
- Also on the Eastern Plains, the combined use of deficit irrigation practices and conservation tillage practices have been employed where well capacity cannot meet ET.
- In the Arkansas Valley, to address impacts of a large Ag to urban water transfer, drip irrigation and new crops were cost-shared by a large municipality to take advantage of reduced ET and specifically, reduced evaporative losses.
- In the South Platte Basin, center pivot irrigation has been widely adopted in recent years to achieve labor savings, but has also resulted in increased irrigation application uniformity and efficiency and changed return flow patterns.
- During the 2002 drought in the South Platte Basin, agricultural users implemented higher levels of irrigation management including reduced set times to minimize runoff and deep percolation in order to meet crop needs under significantly reduced surface water supplies.
- The Grand Valley Water Management Plan was implemented to improve canal hydraulics, which will reduce the need to maintain full canal head to make deliveries to canal users.
- Polyacrylamide (PAM) applications to irrigation canals and ditches on the West Slope and in the Arkansas Valley have shown a 25 percent decrease in seepage losses, while providing sufficient water for the maintenance of riparian plants, e.g., cottonwoods.

Agricultural Water Technology

Sustainable agricultural water conservation technologies and practices are not always the cheapest or the least technically complex. In addition, the impact of agricultural water conservation at the river basin scale can be either beneficial or detrimental to the environment, particularly if irrigated acreage is expanded or consumptive use of water by agriculture is increased. Despite these complexities, the future of U.S. food security and agricultural water security are tightly linked to and dependent to some degree on our ability to use water more efficiently to produce food, fiber, and bioenergy. However, as noted by other authors, the push for more crop per drop may indeed result in more crops, but no additional drops (Burt, 2011).

There is no shortage of information about agricultural water management and technologies available to irrigators and the public. However, published information and research results are scattered throughout an array of sources that are often hard to locate or reconcile. Moreover, the technical language in which most of the research articles and bulletins are published may be a limitation for some audiences seeking information about agricultural water conservation. Hence, there is a great need to compile and make accessible the array of technical information, tools, and water expertise for these audiences.

The Agricultural Water Conservation Clearinghouse Project

To help address the need for better information and understanding of agricultural water conservation, the Northern Plains and Mountains Regional Water Program funded by the USDA National Institute for Food and Agriculture (USDA-NIFA) National Water Program developed the Agricultural Water Conservation Clearinghouse (AWCC) (www.agwaterconservation.colostate.edu). The AWCC (Figure 1) has been instrumental in building partnerships within the academic community. Colorado State University (CSU) Libraries has provided support for the library feature, while the Agricultural Network Information Center (AgNIC) has increased the visibility necessary to build a resource information network for irrigators, agricultural producers, and water resource managers.

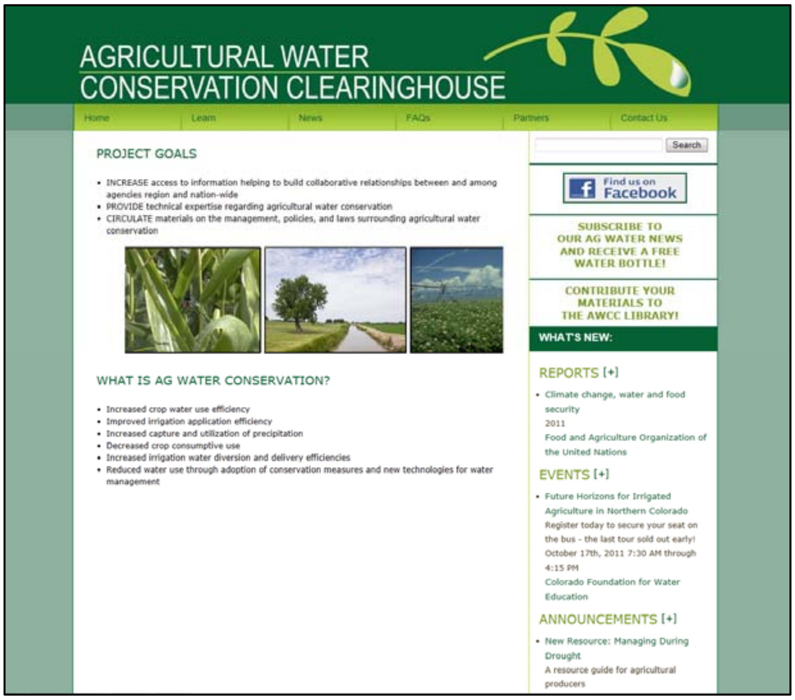

Figure 1. The Agricultural Water Conservation Clearinghouse
(www.agwaterconservation.colostate.edu)

The AWCC is a comprehensive repository of information and resources with a central focus on agricultural water management and conservation. Our vision is to develop a globally recognized information source and community of practice consisting of technical experts and researchers who will collaboratively address the complex issues of agricultural water conservation and water security. The mission of the AWCC is to create a comprehensive, one-stop-shop information resource system on agricultural water conservation by accomplishing two goals: 1) building linkages between water agency partners and experts to share information, research, and outreach activities; and 2) providing the agricultural water community tools and resources to assist them in coping with water management in a changing climate.

Currently, policies applied to saved, conserved, produced, or developed water vary greatly from state to state. Collective and coordinated watershed-scale approaches to managing any conserved water can only enhance national water security. The AWCC has created an online meeting place, where individuals can express ideas, facts, and opinions and where discourse about solutions to agricultural water conservation challenges will open a dialogue between experts, decision makers, and stakeholders. The AWCC supports the development of teams of experts who will be instrumental in discovering information gaps in both technical literature and educational curriculum.

Building partnerships between researchers, educators, practitioners, and industry experts can be instrumental in helping agricultural water users learn about new technologies and how to implement them. These partnerships foster a community of practice that enables communication between different interest groups to share common concerns about agricultural water management and conservation. Connecting water users to the manufacturers of water technologies enhances the possibility of adopting and implementing agricultural water conservation practices in the field, thereby improving farmers' abilities to remain financially solvent and profitable, while at the same time dealing with short and long-term water scarce circumstances. Such exchange and dialogue furthers the formulation of well-thought-out standards for best management practices in agricultural water conservation. This leads to improved data sharing and a better understanding of agricultural water policy implications on basin scale hydrology.

The AWCC is in the form of an interactive website, featuring a searchable library database, an agricultural water expert directory, Frequently Asked Questions (FAQs), and fact sheets. The AWCC Library (Figure 2) is a comprehensive database which identifies current research and educational outreach publications regarding agricultural water policy, agricultural water recovery and recycling, resource economics, crop water use, cropping systems, drought tolerance, irrigation management and systems, irrigation water conveyance e and delivery, phreatophyte management, utilization of marginal water, and water supply, sources and storage. The searchable library database hosts bibliographic records of refereed journal articles, books, reports, theses/dissertations, conference proceedings, and fact sheets and bulletins.

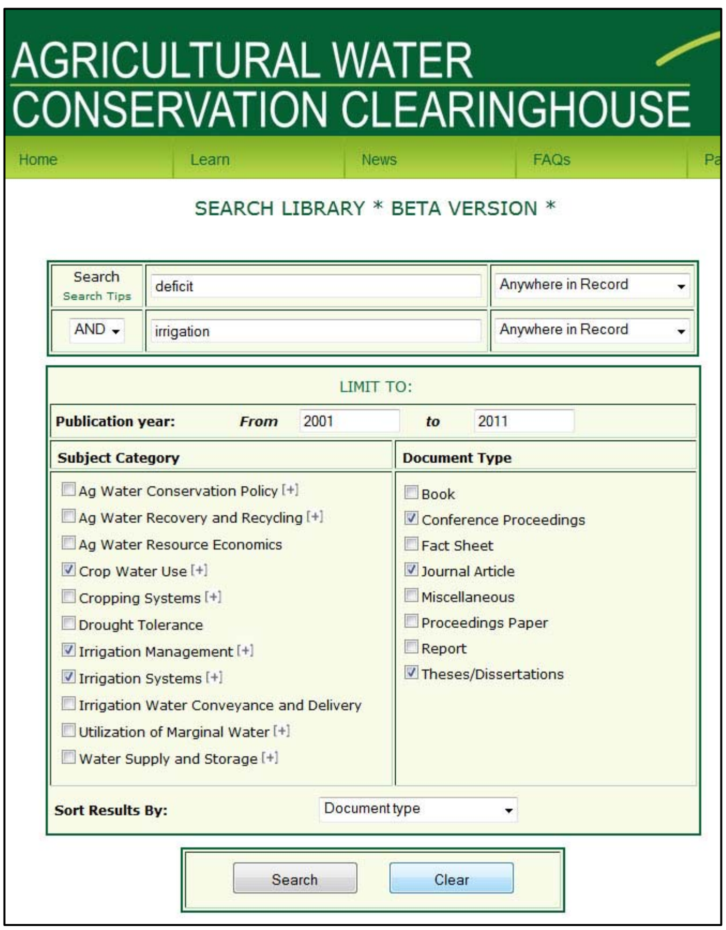

Figure 2. The Agricultural Conservation Clearinghouse Library

The Library is populated by contributions from Extension specialists, research scientists, and educators and provides a refined bibliographic review of agriculture water conservation grey literature. Grey literature refers to materials that cannot be found easily through conventional channels such as publishers, however is frequently original and usually recent. Examples of grey literature include technical reports from government agencies or scientific research groups, working papers from research groups or committees, white papers, or preprints. The term grey literature is often, but not exclusively, used for scientific reports.

The AWCC Library contains over 3,000 entries and the website has been searched by over 21,000 users since it was unveiled in 2008. Request for feedback from users helps strengthen the resource system and expand the network of water resource practitioners from local, state, regional, and national organizations instrumental in providing solutions for water management challenges now and in the future.

In addition, the AWCC website provides current links and contact information to federal and state Agricultural Experiment Stations and Land-Grant Universities, as well as up-to-date information on agricultural water related research centers, irrigation management curricula, workshops, conferences, irrigation tools, software, manuals, guides, calculators, and irrigation schedulers. It also features upcoming events and news related to agricultural water conservation at a regional and national scale.

The AWCC project expands outreach and education efforts by initiating virtual online communities of interest for 1) policy-makers and administrators, 2) agricultural producers, 3) water educators and practitioners, and 4) research scientists. Online forums enable ongoing dialogue about alternatives and the effects of agricultural water policy, and the impacts of basin scale agricultural water conservation. Additionally, online forums foster and promote interaction between the community of practice and communities of interest.

Partnerships are crucial to the success of the AWCC. Besides the collaborating entities, the NPM Regional Water Team has built relationships with the Central Plains Irrigation Association and the U.S. Committee on Irrigation and Drainage Association. A primary outcome of these partnerships is greatly increased access to grey literature published through these organizations. These include proceedings of regional and national conferences and special reports on topics concerning irrigation water management. Until recently, much of this literature has only been available in hard copy and would not be available from traditional library or web searches.

The NPM Regional Water Team has also focused on increasing the knowledge level of private consultants and agency personnel that influence decision making by growers in the NPM Region and around the U.S. To accomplish this, we have published a series of on-line, self-study modules for the professional Certified Crop Adviser (CCA) recertification and proficiency program. Using a pilot survey of CCA Boards in the NPM Region, the NPM Regional Water Team focused the modules on water conservation under limited irrigation and irrigation water quality. The modules were developed through collaboration with research scientists, university faculty from throughout the region, and from neighboring regions. Since the fall of 2009, over 50 Certified Crop Advisers have demonstrated knowledge of limited irrigation and irrigation water quality by correctly answering 70 percent of the questions built into the modules. Over seventy five percent of CCA's completing post module surveys indicated that they would utilize knowledge gained from the series while advising their farmer clients.

CONCLUSION

The outcomes of this project have provided benefits to agricultural water users, natural resource management agencies, policy-makers, the general public, and the industries supporting agricultural water users attempting to address the increasing complexity of agricultural water conservation. While better and more accessible information alone cannot bring the institutional and policy gaps we face in Colorado and other parts of the West, it can help inform the policy discussion as it occurs. The AWCC currently serves the following functions:

- Creates a venue for sharing of information regarding agricultural water conservation; advances awareness about and increasing access to new technologies and best management practices; offers a platform which unites researchers, administrators and policy-makers, practitioners, and educator communities with a commonality of focus of addressing the complexities of agricultural water conservation in the future.
- Provides targeted audiences current information about pressing and complex agricultural water conservation and security challenges, helping them to make more informed decisions and to accurately communicate information about agricultural water use and conservation.
- Identifies gaps in current research, education, and outreach related to agricultural water conservation, thereby helping U.S. federal, state, and local natural resource management and policy-making agencies to better target programs to improve water and food security.
- Informs technical experts, support industries, and educators of the latest agricultural water research and technology, allowing them to better inform their clientele.
- Links industry with the research and education communities.
- Links educators to scientists and technical experts to resource materials.
- Helps agricultural water users make better-informed decisions about their cropping systems.
- Enhances resources and information available through eXtension by expanding virtual and live networks to provide extended outreach.
- Provides support and assistance to policy makers by linking them to experts and current research, as well as to the USDA-NIFA National and Regional Water Programs.

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VERIFYING CONSERVATION ESTIMATES FOR ON-FARM AGRICULTURAL WATER CONSERVATION PROGRAMS

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ABSTRACT

This paper presents an update on the statistical analysis of water use practices on precision leveled rice fields irrigated by the Lower Colorado River Authority (LCRA) Lakeside Irrigation Division. Results from the 2011 analysis confirms again that there is a statistically significant difference in water use between leveled and non-leveled fields (0.33 acre feet of water savings per acre farmed for the first rice crop only). The updated study incorporated and/or refined several additional variables that affect field water use such as other on-farm conservation measures and management practices of individual producers, added a year of data, and will include a separate analysis of the effect of system-wide savings on river diversions. The analysis used a statistical model that incorporated water use and farm practice data over a 4-year period. This study is a conservation verification component of LCRA's HB 1437 Agriculture Water Conservation Program. LCRA partnered with the LBJ School of Public Affairs at the University of Texas to develop the statistical model and analysis presented in this paper.

The House Bill 1437 (HB 1437) Agriculture Water Conservation Program is an innovative way to meet rising municipal demands in Williamson County (located in the Colorado River Basin of Texas), conserve river water used for irrigation, and maintain agriculture productivity. For more information on this program please visit http://www.hb1437.com.

A 2005 implementation study identified land leveling as the first strategy that should be pursued using the funds from this program. The land leveling grant program began in 2006 and from 2006-2010 has funded up to a 30% cost share to precision level 22,086 acres of farm land irrigated with surface water from LCRA. To date an estimated 7,100 acre-feet of water has been conserved as a result of these precision land leveling grants. This study is essential to confirm the accuracy of the water savings estimates, which are being used to calculate the water available for transfer to meet municipal demands. The updated HB1437 short-term plan established a goal of conserving 10,000 acre feet per year by 2014.

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INTRODUCTION

Increasing the effectiveness of water-conserving verification programs has important implications particularly since “most United States legislation focus[es] on encouraging individual farmers to increase irrigation efficiency (Henning et al. 2009, Huffaker 2003).” A consequence of this policy perspective has been the significant amount of public and private funds invested in infrastructure, technology and incentives to reduce irrigated agricultural water use without reducing yields or productivity. Verification programs must be in place to judge the efficacy of numerous policies and resources invested in water-conserving programs. It is in the interest of water regulators and farmers to verify whether and how on-farm and on-district conservations measures save water in the fields and reduce the volume of water pumped from the river. This is an important step in making the case for ongoing investment of federal, regional and state funding to increase irrigation efficiency by improving the irrigation system as well as encouraging individual farmers to improve their farms.

The effectiveness of water conservation programs matter because policy makers, water regulators and utilities are looking at options to transfer water from agricultural-to-urban usage as a way to respond to the increasing water demands of fast growing populations that have limited water resources. It is hard to advocate for water changes from agricultural to municipal uses if reduced amount of water withdrawals from irrigation harm farm productivity significantly. As water becomes scarcer, precipitation patterns more uncertain and pressure for rural-to-urban transfers occur more frequently, legal and institutional mechanisms have to be in place to render water transfers politically, environmentally, socially and economically feasible. Reducing farmers’ consumptive use of irrigation water by implementing conservation measures is one way to justify water transfers that can meet the needs of both municipal and agricultural water users

PROGRAM OVERVIEW

The Agricultural Water Conservation Program (HB1437 program) is a central component of the Lower Colorado River Authority’s (LCRA) water conservation programs for agricultural uses. The HB1437 program is tied to a bill passed by the Texas Legislature in 1999 to authorize the LCRA to transfer up to 25,000 acre-feet of water annually to the Brazos River Basin if the transfer results in “no net loss” of water to the lower Colorado River basin. "No Net Loss” is generally defined as the hydrologic condition where the volume of water transferred is equivalent to the volume of water conserved within the LCRA irrigation divisions. The bill also established a conservation surcharge on the transferred water to fund on-farm and in division agricultural conservation projects within the LCRA irrigation divisions. Additional details of the program history and legislation are available at www.hb1437.com. To account accurately for the conserved water developed through this program, the LCRA depends upon its ability to explain the difference in water use between many potential sources of water savings and the HB1437 conservation programs LCRA implements, such as precision leveling of farmland. The LCRA monitors and evaluates to ensure that sufficient water savings targets are achieved so water can be transferred to the Brazos River Basin with no adverse impact on the Colorado River Basin, as required in the HB1437 legislation.

The LCRA has significantly invested in cost-share programs (HB1437 program) to encourage farmers to implement precision laser-land leveling in an effort to conserve water. According to the LCRA, from 2006 to 2010, it has invested $1.41 million in precision land-leveling 271 fields, totaling 22,086 acres. A major goal of the HB1437 program is to continue to fund precision leveling 2,400 acres per year from 2010 to 2014. This program is run collaboratively with the Natural Resource Conservation Service's Environmental Quality Incentive Program (EQIP) through an interlocal agreement so most HB1437 grant recipients begin by entering into a EQIP contract to receive NRCS cost-share funds to precision level a particular piece of land. When a field is precision graded, the field's natural slopes are reduced or removed; this so-called "uniforming" of land evens out the distribution of water, lowering the required flood depth for a productive rice crop. Eligibility criteria for HB1437 Funds require meeting the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) standards.

This program is a major part of the LCRA's water conservation program for agricultural uses. The program joins individual producers, local soil and water conservation districts, and the NRCS in a collaborative effort to conserve water. The goals of the HB 1437 program are to: 1) Reduce agricultural use of surface water; 2) Plan and implement conservation projects to fulfill obligations of the HB 1437 water sales contract and interbasin transfer permit; 3) Provide grants from the Agricultural Water Conservation Fund to implement water conservation projects; and 4) Provide program performance and conservation metrics to the LCRA Board, water customers, and the public.

This paper reports on the Statistical Testing for Precision Graded Verification, based on a reliable and rigorous water conservation savings verification program for precision leveling in Lakeside Irrigation Division, an irrigation division is situated in Colorado and Wharton County in Texas. This verification study takes on a statistical approach, which is useful to illustrate relationships among the driving factors that influence fields' water usage. To tease-out precision leveling water savings, one needs to separate the effects of factors that can reasonably be expected to influence water usage of fields. Different fields managed by the same farmer may display some similarities in water use. Farmers may differ from one another on the judgments and choices they make about how, when and what amount of water to apply to their fields among other farming decisions they make. Hierarchical Linear Models (HLM) are particularly useful to deal with groupings of fields that share management style as well as when the same data points (fields in this case) do not occur at a regular interval (yearly).

CONSERVATION VERIFICATION STUDY

Studies by others have examined the role of precision leveled fields in agricultural water conservation (Goel et al. 1981, Anderson et al. 1999, Bjornlund et al. 2009, Smith et al. 2007) and have identified several factors affecting conservation estimates including: farmer's age and education, dependence on off-farm work, acres farmed, a field's ownership, the quality of land leveling work and water costs.

The LCRA partnered with the University of Texas at Austin to develop and implement a rigorous statistical methodology to verify water savings from the on-farm conservation practice of precision land leveling while taking into account other water conservation measures and management practices, as currently applied by the farmers, that influence water use.

A first step is to evaluate whether different types of fields have different patterns of water use. To tease-out precision leveling water savings, one needs to separate the effects of factors that can reasonably be expected to influence the water usage of fields. Different fields managed by the same farmer may display some similarities in water use. Farmers may differ from one another on the judgments and choices they make about how, when and what amount of water to apply to their fields among other farming decisions they make.

This analysis separates the 'precision leveling effect' from 'management skills' related to on-farm water usage. To separate the effects of precision leveling in light of farmers' skills and practices, it is important to recognize that a single farmer manages groupings of fields. Although it is plausible that a single farmer may manage one field, information from Lakeside from 2006 to 2010 shows that this one-to-one relationship is unlikely. Table 1 shows that, each year of the study, on average one farmer manages at least four fields. Grouping of fields by farmers supports the idea that different fields managed by the same farmer may display some similarities in their water usage.

Table 1. Number of Fields per Farmer

Year	Average	Maximum
2006	4	10
2007	4	14
2008	4	14
2009	5	14
2010	4	11

Source: Survey and WAMS database 2011

This verification study uses Hierarchical Linear Models (HLM) to quantify the separate effects that a range of factors have on farmers' use of irrigation water. HLM is particularly useful to deal with groupings of fields that share management style as well as when the same data points (fields in this case) do not occur at a regular interval (yearly due to crop rotation).

Data Sources

This study uses three data sources: LCRA data collected for billing purposes from WAMS (Water Application Management System), information collected through a survey of farmers and weather data. This study uses a sample set of approximately 180 fields each year over a five-year period (N=727). The number of precision-leveled fields in the sample funded through the HB1437 program has increased from 5 (2006), to 12 (2007), to 34 (2008), to 43 (2009), to 43 (2010). The three data sources are described below.

Water Application Management System (WAMS) Database. LCRA staff collects information about field characteristics through its annual water contracting process. The LCRA's water customer billing system collects the following information for first and second crop: contract name, field name, year the field was in production, whether the field was in production during the second crop, field acreage (ac), field water use (ac-ft) and number of delivery structures.

Survey data**.** The survey, which elicited information from farmers about fields in production from 2006 to 2010, provides data not otherwise available to LCRA. The survey asks farmers about conservation measures in place, water usage and management decisions that affect water use. The survey was implemented in 2010 and 2011. To increase the accuracy of the conservation verification analysis, during the 2011 survey effort, project staff collected new data (2010) as well as information from farmers who did not respond to the 2010 survey or who submitted an incomplete response. The data collected in the survey represents farmers' self-reported information; field verification of this information was outside of the scope of the study.

The response rate in 2011 was 20 percent higher than that of 2010. A high response rate was achieved as a result of in-person surveys and follow-up phone calls. In 2011, 64 of 73 surveys were completed, which represents 86 percent of the surveys mailed. Over 80 percent of both rice fields in production and planted acreage per year were represented in completed surveys. More than half (62 percent) of all completed surveys were face-to-face questionnaires; the remaining surveys were received via return mail.

Weather data. Weather data were collected from Eagle Lake 7 NE station, Colorado River at Altair and Wharton station from the Lower Colorado River Authority's (LCRA) Hydromet System.[4] Windspeed, solar radiation and humidity were collected from the Eagle Lake Research Center from the Texas A&M AgriLIFE Research Center due to the unreliability of these data collected by LCRA's Hydromet System. Daily weather data was averaged during the average growing season for each station. Growing season refers to the average time between the first and last water delivery of the set of fields within each polygon.

Factors. This study takes a statistical approach to quantify the factors that influence water usage and to illustrate the relationship between factors. The effectiveness of the statistical verification program depends on which factors are included in the analysis. The choice of factors used in evaluating the effect of the quality of leveled land on farm water usage was informed by literature review, local producers, representatives of Lakeside, Garwood and Gulf Coast Irrigation Districts and the LCRA staff. Table 2 shows the factors included in the HLM analysis.

[4] LCRA's website http://hydromet.lcra.org/

Table 2. Factors Included in the HLM Analysis

WHAT ARE THE FACTORS?	
FACTORS	**DESCRIPTION**
PRECISION LEVELING	Whether a field has been precision leveled or not
MULTIPLE INLETS	Number of unmetered water inlets in a field.
RAIN	Average daily precipitation during the average growing season.
EVAPOTRANSPIRA-TION	Average daily evapotranspiration during the average growing season.
CASH	When the person who farms the land pays cash to rent the field from the landowner.
HYBRID*GROWING	Number of days between the first and last water delivery to a field planted with hybrid rice.
NUMBER OF LEVEES	Number of internal levees in a field as part of the irrigation system.
STRAIGHT LEVEES	When internal levees in a field are straight or have a slight bending.

RESULTS

Data from both WAMS and the Survey were used in modeling water usage and savings. When reviewing the results it is important to note that water demand is measured in acre-feet of water used per each acre farmed. An acre-foot is the amount of water required to cover an area of one acre to a depth of one foot.

Factors that influence water use

The 2011 results suggest that farmers who precision leveled a field use on average 0.33 acre-feet per acre less irrigation water than a farmer who does not precision level a field. The 95 percent confidence interval indicates that precision leveling reduces the water usage of a field by no less than 0.14 acre-feet per acre and no more than 0.54 acre feet per acre. The 2011 result is consistent with the 2010 first crop water savings (0.31 acre feet per acre) attributable to precision leveling (see Table 3). The 2011 confidence intervals increase slightly after 116 observations were removed from 2010 to 2011 to achieve a high reliability to all data points (see Figure 1), in that data were verified in the face-to-face survey. Some levee (n=54) and multiple inlet (n=62) observations were dropped to maintain the quality of the data. The results indicate that the water saving estimate for precision leveling is robust, as the values are essentially the same even with an additional year of data and the removal of second crop.

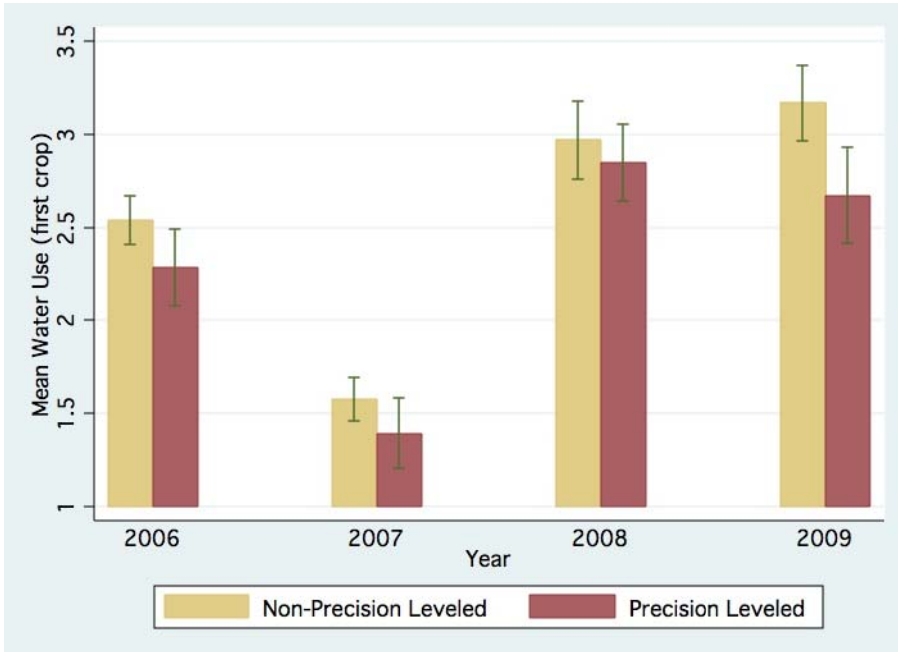

Figure 3. Average Water Use per Year
Source: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

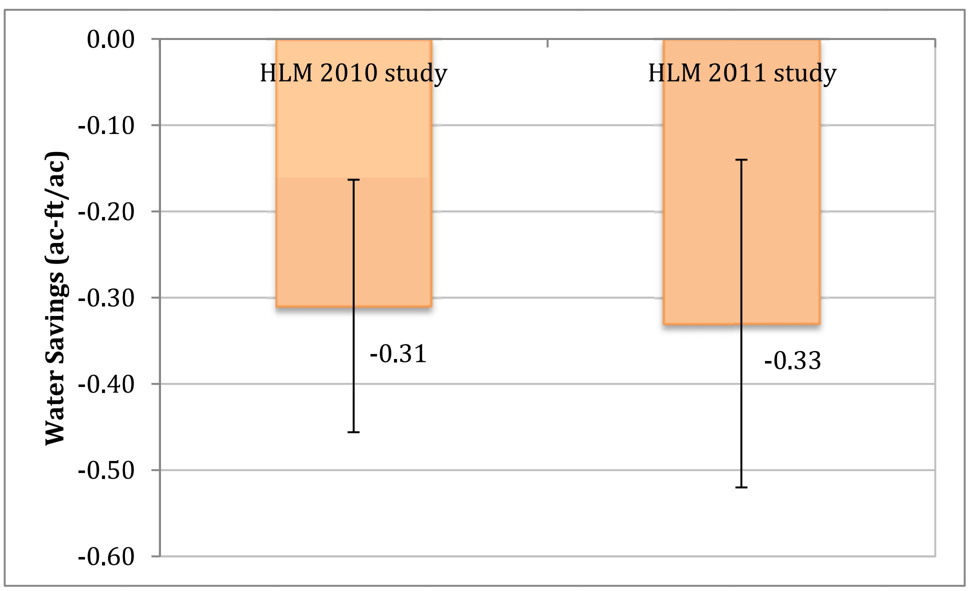

Figure 4. Precision Leveling Water Saving Estimates
Source: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

These results also suggest that if a field is precision leveled, the type of levee (straight or contour) does not affect fields' water usage (see Table 3). In previous research based on agricultural extension experiments, straight levees were associated with lower water usage. This report of 'real' water usage differs because of the 91 precision-leveled fields with a contour levee-system in Lakeside Irrigation Division, almost half (43 percent) are managed by two farmers with superb management practices. These result contrast with

2010 data, which appeared to indicate an interaction between precision leveling and levee type. In 2010 the Interim Report on the "Statistical Testing for Precision Leveling Verification" recommended that the number and type of levees of fields be checked to improve unreliable data and ensure accurate estimates. After the levee type verification and levee count verification, (which improved greatly the accuracy of the levee data), ten percent of the fields were found to have been mis-categorized in terms of their levee type.

Multiple inlets, another conservation farm investment, reduce on-farm water use. The first survey in 2009 gathered multiple inlet data in intervals. To improve the accuracy of the results, the 2010 study collected the exact number of multiple inlets in each LCRA field. Results show that if a field that has one multiple inlet, the use of irrigation water will be reduced by 0.035 acre-feet per acre farmed (see Table 3). Multiple inlets have a statistically significant effect on the water usage of fields. The data from the study indicate a lower rate of water saving than estimates reported by some experimental field studies. One reason is that prior studies evaluate the performance of multiple inlets using a small sample of experimental plots, as field experiments occur in controlled research environments. Researchers seek to control all other influences except for the one technology (variable) tested that could cause a reduction in farmers' water usage. This controlled research approach isolates the effect of the factor that scientists wish to examine. Field experiments are likely to provide high (upper boundary) estimates of water savings.

The quality of the multiple inlet and levee data probably could be improved if data were collected by physical field and not by LCRA aggregate field. LCRA's field boundaries sometimes aggregate a number of different "physical" fields for billing purposes. Water savings attributable to multiple inlets and number of levees is dependent on the quality of these data. Every effort should be made in the 2012 survey (based on 2011 data) to collect multiple inlets and levees at the physical field. This is an important step for LCRA to verify the water savings associated with other conservations measures. This is an additional benefit from this verification study which not only verifies the water savings associated with precision leveling but also from other conservation measures.

The data indicates that, in each year of the study (2006-2010), farmers who cash-rent use less irrigation water per acre farmed than do farmers who share-rent or farm their own land. Results from this verification study show that farmers who cash-rent on average use 0.20 acre-feet per acre less water. When the person who farms the land cash-rents a field, the effect of costs (such as labor and water costs) and profit are tangible and immediate. A farmer who cash-rents bears all the financial risk in the rice production of any given field. Due to the increased financial risk, they are likely to pay more attention to the amount and management of the water they order. This finding is consistent with opinions that farmers who participated in The HB1437 Agricultural Fund Advisory Committee voiced in reaction to what the 2010 data indicated, which seemed contrary to their experience. The improved data (2006-2010) of the 2011 study has results that are consistent with what farmers would expect.

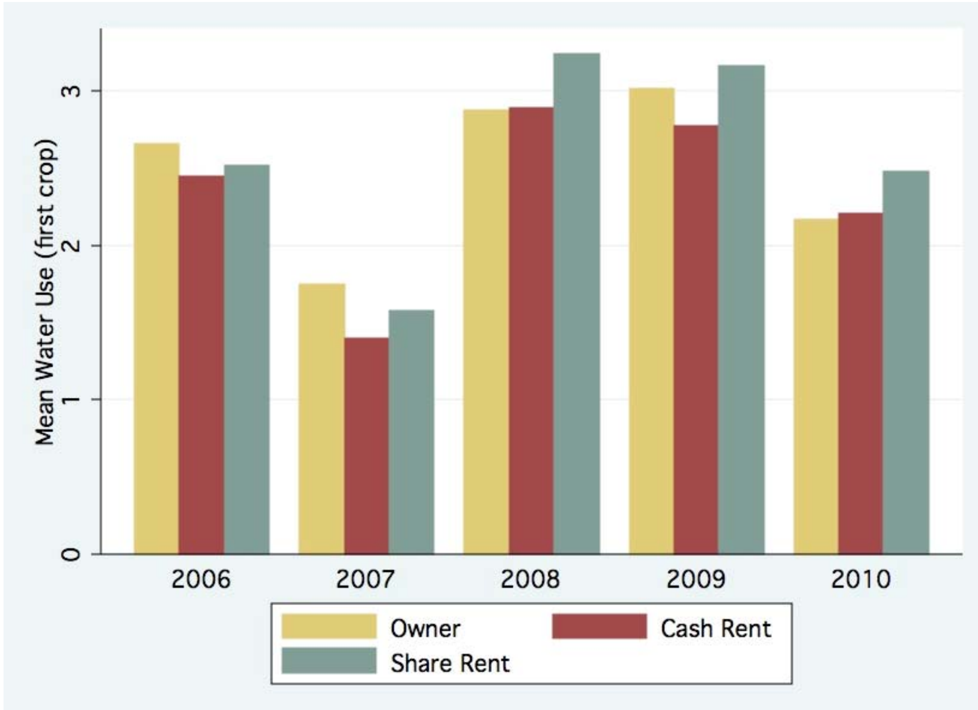

Figure 5. Average Field Water Use by Year and Ownership Stake
Source: Ramirez, A.K., Eaton, D. J. "Statistical Testing for Precision Graded Verification"

In 2011, results also show that farmers that plant hybrid rice uses 0.03 ac-ft/ac more irrigation water for each additional day water is delivered to a field (see Table 3). Hybrid rice in itself does not affect the water usage of a field, but hybrid rice in relation to the growing period does. When farmers plant hybrid rice, this cultivar's longer growing periods lead to higher levels of water usage.

The factors of rainfall and evapotranspiration were included to isolate the effect of precision leveling and other conservation measures from the effect of year-to-year variation in weather. While the previous study in 2009 included temperature, the 2010 study has improved this variable by including the evapotranspiration in the place of temperature. Including evapotranspiration as a factor in the analysis provides more accurate estimates of the marginal effect of year-to-year variation on the water usage of rice fields because higher farm water consumption is not only associated high temperatures but it also influenced by other weather factors (humidity, radiation, wind).

As expected, a one-inch per month increase in rain on average decreases the irrigation water usage of a field by 0.18 acre-feet per acre (see Table 3). This result indicates that farmers reduce the use of irrigation in years with high rainfall, as it contributes to the supply of water. Results also show that in a 'hot' year, with a one-inch per month increase in evapotranspiration, water usage in a field would increase on average by 0.13 acre-feet per acre (see Table 3). Higher farm water usage is associated with high evaporation, which in turn corresponds to noticeable high temperatures and low humidity in a given year. Including evapotranspiration in the verification study accounts for changes in maximum and minimum temperature, humidity, wind speed, and sunshine hours because these factors are used to estimate evapotranspiration.

Table 3. Influence of Factors on the Water Usage of Fields

STATISTICALLY SIGNIFICANT VARIABLES		
FACTORS	SIGN	DESCRIPTION
PRECISION LEVELING	Negative	Precision land leveling, on average, reduces farmers' water usage by 0.33 acre-feet per acre during the 1st crop.
MULTIPLE INLETS	Negative	Having one multiple inlet reduces the water usage of a field by 0.03 acre-feet per acre during the first crop.
RAIN	Negative	A one-inch per month increases in rain, on average decreases the water usage of a field by 0.18 acre-feet per acre.
EVAPOTRANSPIRA-TION	Positive	A one-inch per month increase in evapotranspiration, on average increases the water usage of a field by 0.13 acre-feet per acre.
CASH	Negative	Farmers who cash-rent their land, from planting to harvest during the first crop, use 0.20 acre-feet of water less than farmers who share-rent or farm land they own.
HYBRID*DIFF_GROW2	Positive	Farmers that plant hybrid rice uses 0.03 acre-feet per acre more irrigation water for each additional day water is delivered to a field.
NOT STATISTICALLY SIGNIFICANT VARIABLES		
FACTORS	SIGN	DESCRIPTION
NUMBER OF LEVEES	Positive	A one levee increase in the number of internal levees in a field, on average increases the water usage of a field by 0.001 acre-feet per acre
STRAIGHT LEVEES	Positive	A straight-levee irrigation system increases the water use of a field by 0.12 acre-feet per acre.

RECOMMENDATIONS

Second Crop Water Savings

An HLM analysis of only the second crop is an important next step to estimate precision leveling water savings only during the second crop. If the LCRA can gather water use and farm practices information for a sixth year (2011) it will be possible to compute for the first time a water savings coefficient for precision leveling for the second crop using the methodology delineated in “Statistical Testing for Precision Graded Verification.” Estimating the total effects of precision leveling that include savings during the second crop, in addition to the water savings coefficient for the first crop is an important step to revise LCRA’s current coefficient of 0.75 acre-feet of water saved per acre leveled for both crops.

Survey 2011

A new and more complete data set (2006-2011) will not only improve the quality, accuracy and reliability of precision leveling water savings, but also increase the sample size necessary to separate precision-leveling water savings during the second crop. Because the accuracy of the results of this conservation verification analysis depends on the information collected, this study involves the revision of the survey instrument and the implementation of face-to-face interviews to cross check and to expand existing information with an additional year of data (2011). The 2011 survey data is necessary to estimate the second crop water savings from precision-leveled fields.

Multiple Inlets

This verification study has the added benefit of estimating water savings for other conservation such as multiple inlets. Multiple inlets are a less costly conservation measure than precision leveling and may have comparable water savings. LCRA's field boundaries sometimes aggregate a number of different "physical" fields for billing purposes. If the data were to be collected at the individual field level, instead of at the aggregated billing field level, the LCRA could develop two conservations measures (precision leveling and multiple inlets) with verified water savings to better plan and invest in conservation programs.

Multiple inlets is a conservation measure LCRA can invest on to further reduce the volume of water used by agricultural customers. Multiple inlets could eventually complement precision leveling if and when precision-leveled acreage reaches a saturation point and remains steady over time.

Water savings attributable to multiple inlets and number of levees is dependent on the quality of these data. Collecting multiple inlets and levee data at the physical field level is necessary to achieve an accurate water savings associated with multiple inlets. This is an additional benefit from this verification study which not only verifies the water savings associated with precision leveling but also from other conservation measures.

CONCLUSION

LCRA is delivering on its promise to evaluate its precision-leveling conservation program in Lakeside Irrigation Division. So far, the verification study provides a water saving estimate for precision leveling that is robust, as the values are essentially the same in the 2010 study as in the 2011 study. The sample changed between the 2010 to the 2011 study with an additional year of data (2010), the removal of second crop and an overall increase in fields surveyed each year (2006-2009).

Progress in estimating the relationship between precision leveling and the water usage of fields should be directed to estimate water savings during the second crop. With better data, LCRA will have precision leveling water savings coefficients for both the first and second crop to compare with the current 0.75 ac-ft/ac coefficient. Absence of adequate data on multiple inlets and levees by physical field also hampers LCRA's ability to capitalize on the added benefit of this verification study to estimate water savings attributable to other conservation measures besides precision leveling. With additional data on multiple inlets LCRA will be in a stronger position to evaluate the feasibility of funding additional water conservation measures through the HB1437 grant program. With verified water savings from precision leveling, LCRA can ensure that sufficient water savings targets are achieved so water can be transferred to the Brazos River Basin with no adverse impact on the Colorado River Basin, as required in the HB1437 legislation.

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EQUIPMENT AND WATER SUPPLY CHANGES PRODUCE INCREASED EFFICIENCY AND NUT YIELDS

Herbert W. Greydanus P.E.[1]

ABSTRACT

Pioneer Ranch Partnership LLC operates an 80-acre almond ranch in the Turlock Irrigation District (TID) in Central California. Ground water from two wells has been applied with Rainbird sprinklers. The lower tree canopies are wetted with Rainbirds and canker disease frequently develops. Ground water requires buffering with acid to offset carbonates.

Irrigation improvements were made in stages. First, Rainbird sprinklers were replaced with micro sprinklers at each tree. A filter was installed at each well. The second stage included a single central pump at the TID pipeline on the Ranch with pipelines to each well and hookup to the filters and micro sprinkler lines. The 75-HP well motors and pumps were kept operable for frost control and for backup supply in water short years.

A single 75-HP pump for surface water is adequate to supply all low-pressure micro sprinklers. Irrigation labor has been reduced by 50 percent. The seasonal water applications with micro sprinklers during 2009 and 2010 were 135 acre-feet and 175 acre-feet, respectively. For an average of 155 acre-feet this was a reduction of about 33 percent. Electricity use was reduced from 61,000 KWH to an average of 16,180 KWH for 2010 and 2011. It is no longer necessary to buy "risk-handling" acid. The annual loss of 40 diseased trees will be avoided. Tree foliage looks significantly healthier. It is estimated that there will be a 10 percent increase in nut yield.

The capital cost was about $86,000. Based on 6 percent interest, reduced operating costs and increase in yield, the capital cost can be recovered in less than three years.

INTRODUCTION

Using ground water for irrigation provides significant flexibility in scheduling applications-both seasonally and daily. When its use involves some unique management issues and anticipated increase in the cost of power, as was the case for Pioneer Ranch, it became prudent to examine the merits of switching to surface water which is available from Turlock Irrigation District (TID). Annual water assessments were already being paid and the Ranch is entitled to buy TID water. This paper describes the factors which were evaluated and the benefit-cost analyses which led to changes in facilities and water use.

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ALMOND CULTURE

Almonds are a major tree crop in California which produced about 1.17 billion pounds from 705,000 acres in 2010. Production increased 23 percent to 1.44 billion pounds in 2011. Stanislaus County, in which Turlock Irrigation District and Pioneer Ranch are located, had about 97,600 acres or 14 percent of the total acreage in 2010. Almond trees bloom in February-March and are harvested in August-September depending on the variety. Damaging frosts can occur during the bloom. Honey bees for pollination, 160 hives for Pioneer Ranch, and irrigation water are two key inputs for successful crops. Almonds are harvested by mechanical shaking of the entire tree when the hulls have opened. The nuts, mostly still in the hulls, are swept into windrows and then loaded onto trucks for a trip to the huller. The hulls are first removed and then the nuts are passed through a cracker where meats (kernels) are separated from the shells. The nuts are then shipped to the processor--in our case Blue Diamond Growers. Almond hulls, which have about two-thirds of the nutrient value of alfalfa, are sold for incorporation into dairy cow feed.

Almond trees reach full production in about 8-10 years and begin to decline after about 20 years. They are usually replaced after about 25 years depending on the benefit/cost comparisons. Tree spacings are becoming smaller as more tailored equipment and management have improved yields. Trees on Pioneer Ranch are on 22-foot centers or 90 trees per acre.

RANCH DESCRIPTION

The 80-acre Ranch is the south half of a quarter section. The deep soils are generally sandy silts with good drainage and are ideal for tree crops. Half of the trees were replanted in 2000 and the other half in 2004.

A 36-inch gravity pipeline of TID passes through the center of the Ranch in a westerly direction. A 16-inch well is located at the center of each half of the Ranch. The pumping lift is about 140 feet.

Vandalism and copper theft are big problems on farms throughout the Central Valley and the Ranch has had its share. Well sites and equipment have been enclosed in security fencing with motion sensors which are monitored on a 24-hour basis. Rainbird sprinkler heads have been used as “bowling pins” for dirt bike riders. There is no one in residence on the Ranch and the perimeter is now fenced.

IRRIGATION PRACTICE ON PIONEER RANCH

The first seasonal irrigation on Pioneer Ranch is generally in April. Actual timing depends on the amount of winter rainfall and the moisture available in the tree root zone as shown from soil moisture sensors. In 2012, due to the lack of rain, trees were irrigated in January. The last irrigation is generally after harvest in late October.

Until 2010 Pioneer Ranch was irrigated with ground water from two wells. Prior to 2009 water was applied with Rainbird sprinklers. These sprinklers covered most of the land surface and wetted the lower tree canopies. Canker disease developed in some of the trees. It is a particular problem in young trees. Excess moisture on the trees also creates problems with hull rot.

The ground water at the Ranch is quite high in carbonates and requires addition of acid for neutralization. Liquid NpHURIC, a formulation of urea and sulfuric acid, was used. (The technical name for the formulation is dicarbamide dihydrogen sulfate solution.) Special care must be taken in handling the acid and there is always a risk of injury to a worker.

CHANGES IN IRRGATION PRACTICE

The primary water management concerns were the canker disease problem and the less than fully effective application of water from Rainbird sprinklers to areas beyond the tree root zone. Rainbird sprinklers were replaced with micro sprinklers at each tree. It was also necessary to install filters at each well as some sand was pumped from the wells and micro sprinklers would become clogged. There was a significant reduction in use of power for pumping with lower pressure requirements of the micro sprinklers and less water application. There was also less drawdown in the wells with lower rates of water application.

The second step was conversion from ground water to surface water from the TID pipeline. A single pump with a 75-HP motor was installed and a totalizing flow meter was placed in the discharge line. Pipelines about 330 feet long were constructed to connect with equipment at each of the well sites. Water from the TID pipeline comes from a canal and it was necessary to construct a turnout box with a moss screen. The filters at the wells have a continuous discharge of about 100 gallons per minute (gpm) of filtrate that is conveyed in a 2-inch pipe to the TID pipeline downstream of the Ranch. This avoids ponding and interference with farm operations near the well sites and also results in no waste of water from the filters.

The existing well equipment was retained for back-up water for frost protection in the spring when the trees are in bloom and nuts are forming. Water from the sprinklers adds heat to the tree environment which can be enough to prevent frost damage if it does not freeze too hard. The wells also are available for post-harvest irrigation in dry years if TID does not have enough water. Switching for electric power service is arranged so that only the central surface water pump or the two wells can be operated at any one time. It is thus possible to avoid paying for increasing the connected load above that of the two pumps. The pumps will be operated annually to ensure water will be available when needed, particularly for frost control.

In accordance with public health regulations and for prudent management of the wells, a self-closing check valve was installed at each well to prevent surface water from entering the well. It is possible, however, to pump ground water into the TID pipeline, if needed by TID to serve downstream users in critically dry years.

Use of micro sprinklers makes it possible to irrigate all of the Ranch at one time. However, with micro sprinklers it is necessary to irrigate one or two times more each season than with Rainbird sprinklers. The Ranch operator's headquarters are about seven miles away from the Ranch and there are significant savings in travel time for workers to check on irrigation equipment. By being able to irrigate all of the ranch at one time, there are net savings in labor hours with the use of micro sprinklers.

Power requirements are much lower using surface water because micro sprinkler pressures are lower and it is not any longer necessary to pump ground water to the land surface. During years when Rainbird sprinklers were used the seasonal application of water was about 36 inches or 240 acre-feet. With micro sprinklers the amount of applied water was 135 acre-feet in 2010 and 175 acre-feet in 2010 for an average of 155 acre-feet or nearly 24 inches of water.

New Pump and Turnout/Moss Screen Box

950-GPM Filter Connected to Both A Well and TID Water

CAPITAL COSTS

Design and construction was provided by Waterford Irrigation and Supply, Inc., a local consulting firm. Work was scheduled and managed by the Ranch operator, Piazza Farms, to fit in with irrigation and ranch operations.

Stage 1 work, replacement of Rainbird sprinklers with micro sprinklers and filters at the wells, was completed in 2009. Stage 2 work, construction of the central surface water pumping plant, power supply and pipelines to the two well sites, was completed in 2010. The cost of each stage is shown in the following tabulation:

Costs of Installed Equipment

Item	Stage 1	Stage 2
Micro sprinklers	$19,510	
Two 950-gpm, 8-inch filters	26,640	
75HP Pump		$8,740
Pump and Appurtenances Installation		21,700
Electrical Controls Installation		8,050
Totals	$46,150	$38,490

SAVINGS AND BENEFITS

There are both quantifiable and qualitative benefits from conversion from ground water to surface water.

Power

Power savings may be measured by the reduction in energy use. The connected load billed by TID remains the same as with ground water use because, while the two well motors remain on line for backup water, controls at the surface water pump prevent concurrent operation with the well pumps.

Energy use in 2008, when Rainbird sprinklers were still used with wells, was 61,440 KWH. In 2010 the use was 14,120 KWH and in 2011 it was 18,240 KWH. With an average post-project use of about 16,000 KWH, there will be a reduction of about 45,000 KWH per year or approximately a 75 percent saving.

TID connected load and energy charges vary by season. Charges are $0.0716/KWH and $1.66 per connected HP during March-October and $0.1654/KWH and no load charges during November-February. The average unit cost for energy used on the Ranch in 2011, including public benefits adjustments and state surcharge, was $0.0923/KWH. This rate represents savings of about $4,150 per year for 45,000 KWH.

Water Quality

With surface water for irrigation it is no longer necessary to buy acid to neutralize the carbonates in ground water. The average cost of acid in 2008 and 2009 was about $8,000.

The future loss of trees due to canker disease can be estimated by the rate of loss over eight years prior to the use of micro sprinklers. The loss from 3,500 trees planted in year 2000 was about 20 trees per year. This rate would result in an annual loss of 40 trees for the entire Ranch. Based on insurance payments for trees lost in accidents the value of each producing tree is about $150. For an average annual loss of 40 trees this is equivalent to $6,000 per year.

Water Cost

In addition to annual assessments on land in TID there is a charge for delivered water. For Pioneer Ranch the charge in 2011 was $2,070.

Labor for Irrigation

Irrigation labor when Rainbird sprinklers were used required about four hours for each turn-on and turn-off for each well. With an average irrigation interval of 15 days over eight months the total labor is slightly over 260 hours. The average cost of labor is $12.00 per hour for a total cost of $3,120 per season.

Micro sprinklers reduce the number of hours per irrigation from 16 to 8 but increase the frequency from 15-day intervals to 10-day intervals. Over eight months there will be 16 irrigations requiring a total of 128 hours at a cost of $1,540 resulting in saving $1,580 per season.

Nut Yield

Specific quantitative data on increases in nut yields resulting from more uniform application of water and the high quality of surface water from the Tuolumne River are not identifiable because the trees were maturing and increasing in yield during the changes in equipment. The Ranch Operator, who operates several ranches and hundreds of acres of almonds, conservatively estimates that there will be a 10 percent increase in yield. The tree foliage looks healthier than when ground water was used.

One-half of the trees are at full production at eleven years of age. The other half are seven years old and are not up to full production. The Ranch produced 143,00 pounds and 141,000 pounds of good meats in 2009 and 2010, respectively. Based on 10 percent attributable to better water applied more efficiently the increase was 14,000 pounds. At full tree maturity of all trees, an increase of 15,000 pounds is a conservative estimate. The current payment rates for Ranch varieties are about $1.90 per pound resulting in an estimated benefit of $28,500 per year.

ECONOMIC ANALYSIS

The foregoing costs and savings/benefits are summarized as follows:

Capital Improvements	
Stage 1	$46,150
Stage 2	38,490
Total	$85,540

Annual Savings/Benefits and Costs	
Avoided acid purchase savings	$8,000
Power savings	4,150
Reduced irrigation labor costs	1,580
Reduced loss of diseased tress	6,000
Increase yield of nuts	28,500
Water charge	(2,070)
Total	$46,160

A valid economic evaluation requires that costs and benefits be based at the same point in time. Using costs at the time of construction requires that future savings/benefits be based on present worth. It is also necessary to include the cost of future maintenance of equipment. It is conservatively estimated that annual maintenance costs would not exceed five percent of the capital cost during a 20-year equipment life-evaluation period. This allowance would be about $4,300 per year.

The following tabulation shows present worth of costs and net savings/benefits based on six percent interest over a 20-year period:

Capital costs	$85,540
Maintenance	49,320
Total present worth of costs	$134,860
Present Worth of Net Savings/Benefits	$529,460

The foregoing values indicate a benefit-cost ratio of 3.9:1. It is recognized that about 75 percent of the benefits are in the estimated 10 percent increase in nut yields. However, even if the increase is only five percent, the benefit-cost ratio would be 2.7:l.

The estimated annual savings/benefits of $46,160 indicates that, conservatively, the capital costs of $85,540 will be recovered in less that three years, even if there is any abnormal spring weather.

SUMMARY

The loss of newly planted trees from canker disease, the costs and risks of buying and handling acid and the anticipated increase in power rates caused re-thinking of continued use of ground water. (TID did raise power rates about 20 percent beginning in 2009.) Tree disease and the cost of power were first addressed by switching from Rainbird sprinklers to micro sprinklers. The availability of high quality surface water and power through the center of the Ranch provided a unique opportunity to modify the irrigation equipment and cease use of acid for neutralization of carbonates in ground water.

The ability to draw on two sources of water provides flexibility and enhances the value of the Ranch. An agricultural land appraiser opined that the increase in value would be at least as great as the capital cost inasmuch as a new owner would need to invest a like amount to achieve comparable flexibility and supply assurance.

The ability to irrigate all of the Ranch at one time reduces the time requirements and attention of the Ranch manager as well as the irrigation labor costs.

An additional, but difficult to quantify in terms of the timing and amount, will be savings from delay of well pump and motor repairs which can be quite expensive.

Developed water supplies in California are not enough to meet needs even in years with normal precipitation. Priorities for environmental goals in some situations are higher than for agricultural supplies. Increasing attention is being focused by the State legislature and the State Water Resources Control Board, which issues and manages surface water rights permits, on ground water use and rights. The retained ability to pump ground water will allow the Ranch to forego its surface water in extremely dry years when TID may need to ration water. Such return to ground water will free-up water for other users.

The changes on Pioneer Ranch have been noted by other almond growers who have similar water supply situations. It is expected that others will follow the Pioneer Ranch LLC example.

RED BRIDGE WATER REUSE PROJECT

Chad Brown P.E.[1]
Jamison Thornton[2]

ABSTRACT

The Strawberry High Line Canal Company (SHLCC) recently completed the Red Bridge Water Reuse Project. The project developed approximately 10 cfs of an underutilized water supply in Spring Creek, near Payson, Utah. The water is primarily return flow from the United States Bureau of Reclamation's (USBR) Strawberry Valley Project lands. The return flows, which SHLCC has rights to, had not been fully utilized before the project. The majority of the return flows were being released into Utah Lake.

The project constructed a new diversion structure on Spring Creek to replace the existing one. A new pump station, pipeline, and pond were constructed in conjunction with the new diversion. The pumped water is delivered to Laterals 20 and 20S of SHLCCs system. The lands serviced by Laterals 20 and 20S had previously limited water supply, but are now able to receive a full supply. By supplying water to these Laterals, water higher in the system can now be provided to municipal users for their secondary water systems and irrigators within the service area.

The Red Bridge Water Reuse Project better manages SHLCC's water. There is 1,800 ac-ft of increased supply, which became 1,800 ac-ft of indirect water conservation. This is reuse water that is being marketed to existing SHLCC stockholders. The increase in water supply is approximately three percent of the total SHLCC water supply. Water is now available to shareholders elsewhere within the system or left in storage within the Strawberry Reservoir for future use.

INTRODUCTION

The main goal of the Red Bridge Water Reuse Project was to fully utilize SHLCC's water right within Spring Creek. The water right had been put to beneficial use for flood irrigation but was not being fully utilized. Not all of the water supply could be used under current conditions and was flowing into Utah Lake. SHLCC saw the potential to supplement shareholders located on Lateral 20 and 20S with additional water, as well as replacing some of their existing water supply. By replacing the existing water supply, this allowed water to be used higher in the system or held in Strawberry Reservoir for future use. The project achieved this specified goal.

SHLCC needed the ability to pump water from Spring Creek to the newly piped Lateral 20S where it could be distributed to shareholders there as well as Lateral 20. This project

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provided SHLCC with a way to put to use all of their water rights, including their high flow water right.

The water right for this project is Utah Water Right #51-2577 which has a priority date of 08/25/1921 and an amount of 9.867 cfs or 2,368.0 ac-ft. The Red Bridge Project has the ability to take full advantage of this right, but currently is only using 1,800 ac-ft in the following manner:

- Irrigation: 600 ac-ft delivered to approximately 4,500 acres.
- M&I: 1,200 ac-ft delivered to secondary connections in the Payson area, which has a current population of about 12,700.

HISTORY

The Strawberry High Line Canal Company (SHLCC) was formed to deliver the United States Bureau of Reclamation's (USBR) Strawberry Valley Project (SVP) water to landowners in the areas of Payson, Genola, Salem, Spring Lake, and West Mountain, Utah. SHLCC also receives water from the USBR's Bonneville Unit of the Central Utah Project (CUP). It has contracts with the USBR for operation and maintenance of the High Line unit of the SVP. SHLCC water is used primarily for municipal and irrigation purposes (Figure 1).

SHLCC delivers an average annual water supply of 56,300 ac-ft. It has approximately 17 miles of canals, many miles of laterals, and 30 storage ponds. They service 17,500 acres of agricultural land, as well as 22,000 people in southern Utah County. Approximately sixty percent of the system is irrigated by pressurized irrigation and the remaining forty percent by flood irrigation (Figure 2).

PLANNING

Funding for the Red Bridge Project was supplemented through the USBRs Water 2025 Challenge Grant Program. SHLCC received a grant for $260,000 from the program. The Challenge Grant Program was established to assist "irrigation and water districts that want to leverage their money and resources in partnership with Reclamation, to make more efficient use of existing water supplies through water conservation, efficiency and water marketing projects." [3]

Eligible projects had to be completed within 24 months of receiving funding and reduce future water conflict. The Red Bridge Water Reuse Project is located in an area identified by the Bureau of Reclamation as a hot spot due to its rapid growth and limited existing water supplies. By utilizing the existing water supply, SHLCC was able to reduce future water conflict through this project.

By receiving the grant from USBR, SHLCC was able to execute the project with a total cost just over $750,000. SHLCC contributed $490,000 to the project from their general

[3] http://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=2541

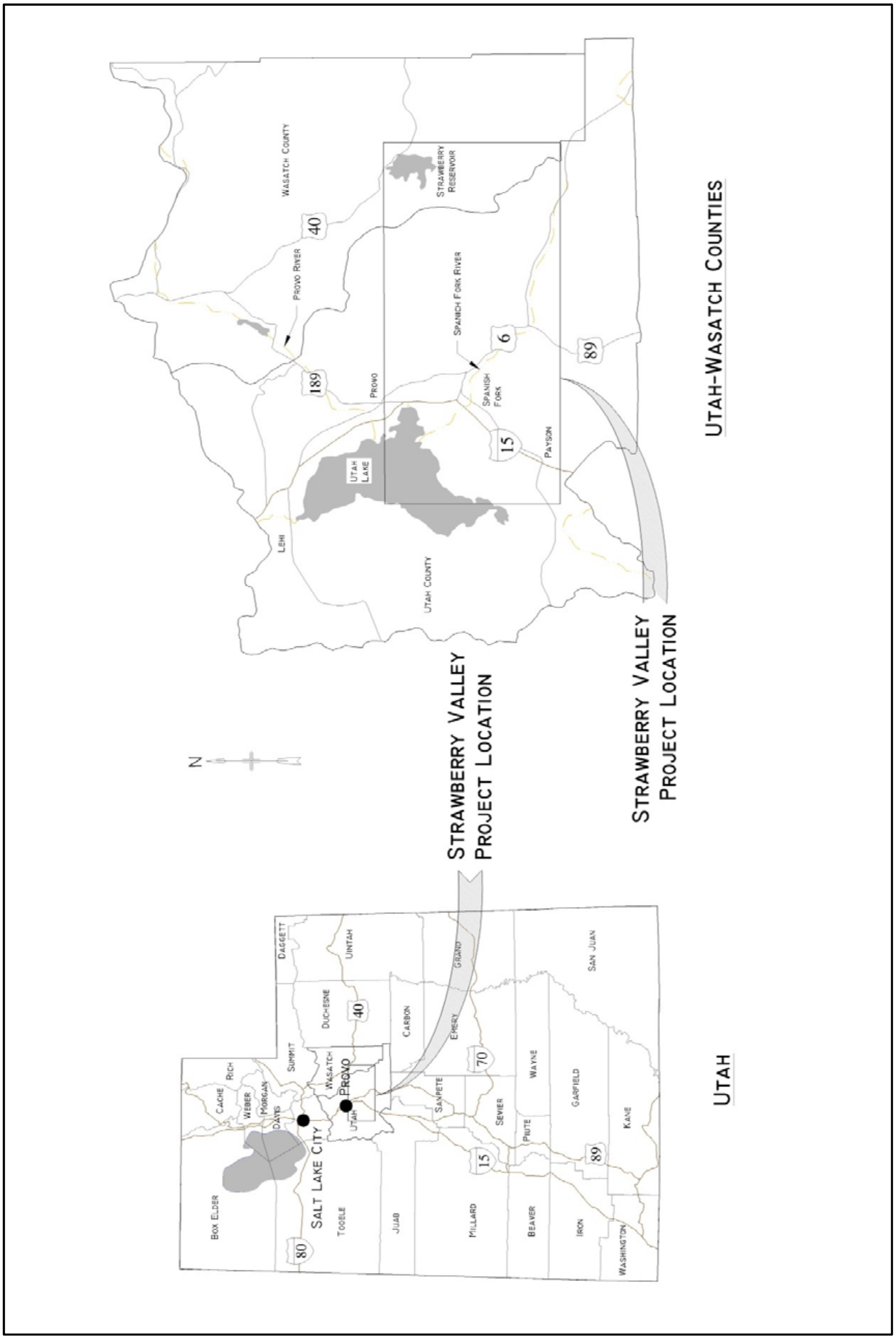

Figure 1. Strawberry Valley Project Area

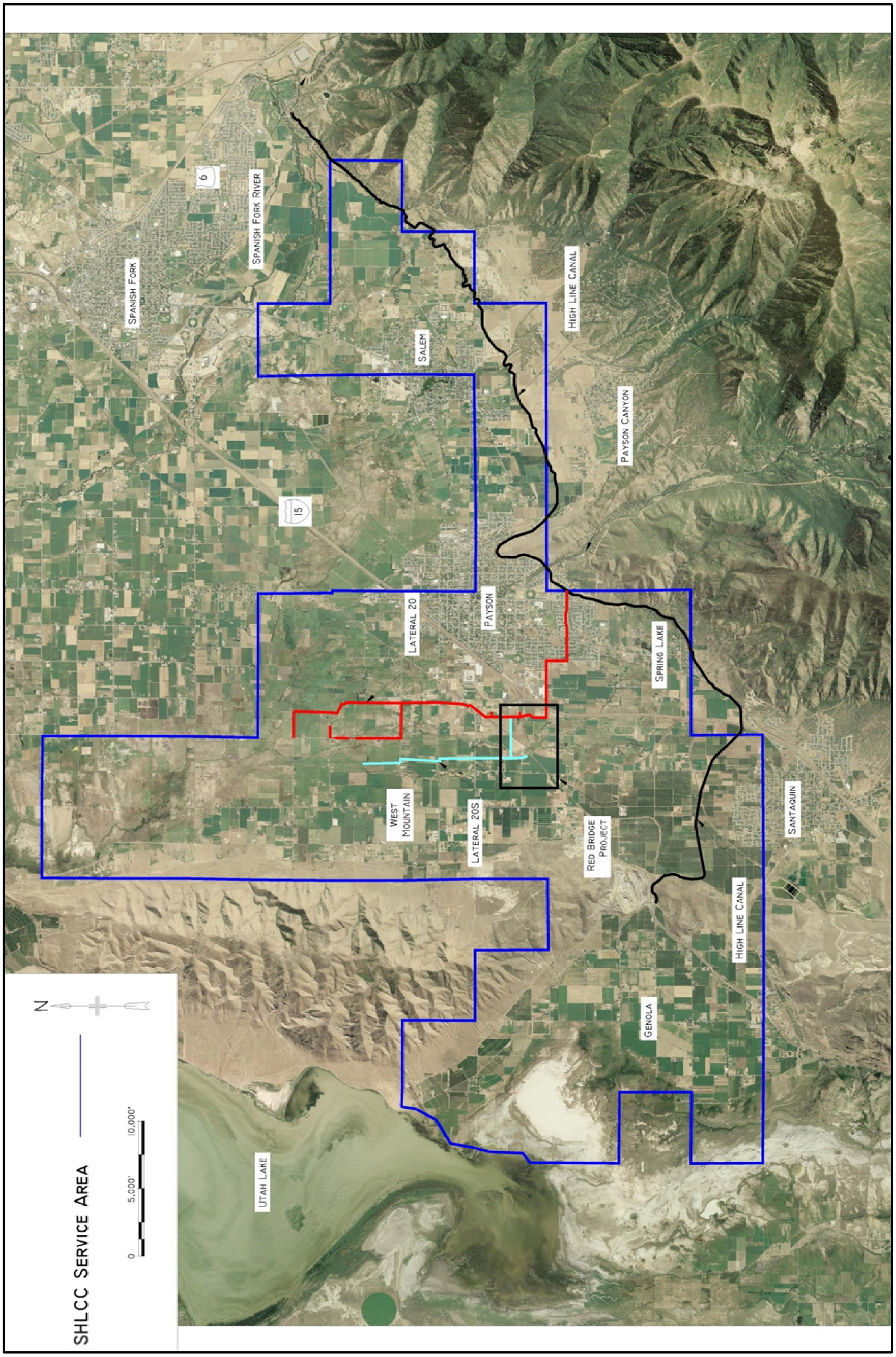

Figure 2. Strawberry High Line Canal Company Service Area

funds account. Project planning and budgeting had to be considered to set aside the necessary funds to pay for the Red Bridge Water Reuse Project (Figure 3).

During the planning phase of the project, coordination with several agencies and private land owners was critical. Coordination included: the USBR, the Union Pacific Railroad, South Utah Valley Electric Service District, the State Historical Preservation Office, Utah Dam Safety Office and Mr. Gerald Finch. Coordination with Mr. Finch occurred to acquire the necessary property for the project. The SHLCC shareholders were also involved to express their opinions for, or against the project.

Before the project could receive funding the USBR performed an Environmental Assessment in accordance with NEPA compliance. The necessary biological and archeological surveys were performed as well. Since the project received federal funding, these items were a requirement for the project.

DESIGN & CONSTRUCTION

Diversion Structure

An entirely new diversion structure was built in the same location as the original diversion structure. The original structure was used to divert water to an open ditch that supplied water for flood irrigation. The new diversion structure for the Red Bridge Water Reuse Project serves the same purpose but now diverts water to a regulating pond. The structure dams the flow in Spring Creek, allowing the backed up water to be sent through a 24-inch HDPE pipe to the pond. The structure includes a 12-foot weir that allows high flows to continue down Spring Creek. A slide gate, adjacent to the weir, was installed to flush built-up sediment down Spring Creek. The new diversion was retrofitted to the wing walls of the adjacent railroad bridge (Figure 4).

Pond

A regulating pond was constructed as part of the project. The pond is supplied through the 24-inch HDPE pipeline from Spring Creek at the same location as water was previously supplied to the open irrigation ditch. The ditch was abandoned and the pond constructed in its place.

The pond was constructed below the native ground surface. The normal water surface of the reservoir is at the same elevation as the water surface of the irrigation ditch that previously occupied this space. A spillway has not been designed for the reservoir since the water surface elevation will be controlled by the water surface elevation of Spring Creek. A control gate at the diversion structure is used to regulate flow into the pond. The pond is designed with three feet of freeboard as a safety precaution. The outlet from the pond is a 42-inch HDPE outlet pipe connected to three pumps.

Figure 3. Red Bridge Project Location

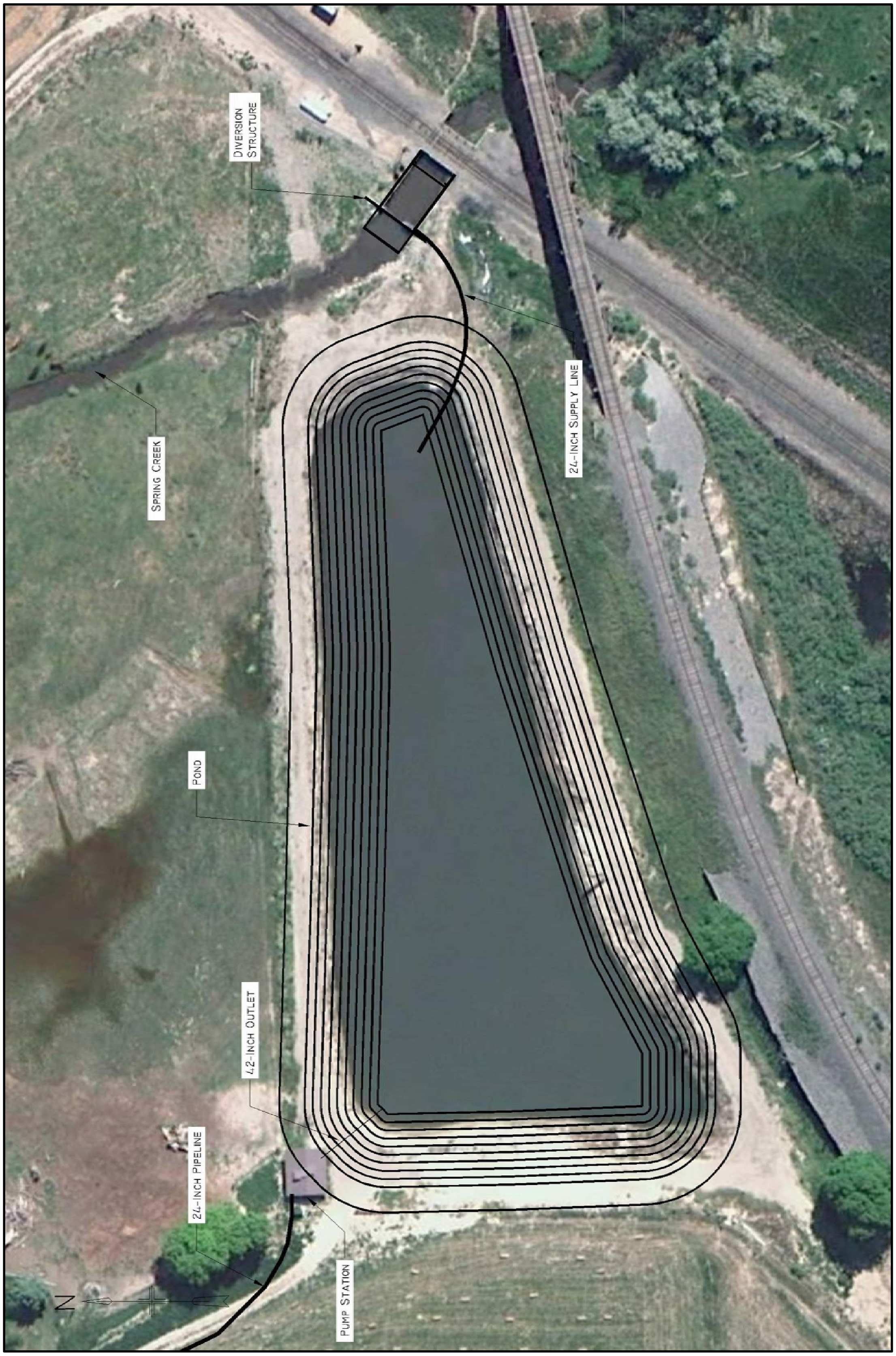

Figure 4. Red Bridge Project Site

Pump Station

Three Flowserve vertical turbine pumps, capable of pumping a total of 10 cfs (4,500 gpm), pressurize a distribution line and convey water to SHLCC shareholders through a 24-inch HDPE pipeline. The pumps are equipped with variable speed drives in order to efficiently provide water to shareholders when needed. They pump 120 feet of head in order to push the water over a high point in the system and maintain the desired pressure in the pipeline.

Pipeline

A 24-inch HDPE pipeline was installed from the pump station to Lateral 20S. The pipeline is 1,250 feet long. The pipeline was needed to convey water from Spring Creek to the newly piped Lateral 20S. This allowed the water to be used in the Lateral 20S service area as well as the Lateral 20 service area.

Survey Control

A survey control was installed throughout the area. Established control points were set up on all corners of Section 13; Township 9S; Range 1E. Digital Elevation Models (DEM) were also used for survey control on the project. The surveyed control points were used to create the design drawings used during construction. A few additional survey control points were used during construction to help monitor elevation and grade.

Gates

Gate selection was based on a design flow of 10 cfs, along with additional capacity to handle more as demands increase in the future. With future expansion in mind, a 24-inch Waterman sluice gate was installed. An automatic gate control can be installed in the future as additional funds become available. The actuators will regulate flows to the pond without the need for manual operation.

A sluice was also designed adjacent to the diversion structure weir in order to flush out any sediment that would build up behind the structure. The sluice gate dimensions were designed based on the dimensions of the overflow weir. The dimensions of the sluice gate were 48 inches by 40 inches.

Utility Location

During the design phase, all local utilities were contacted, and existing utilities within the project area were located in the field. Care was taken to reduce conflicts with existing utilities within the area.

Quantity of Flow

Based on discussions with SHLCC it was determined that 100 cfs would be expected to pass across the overflow weir. This flow governed the design of the diversion structure. The flow was verified by searching peak flow records.

Construction Considerations

SHLCC performed the majority of the construction of the Red Bridge Water Reuse Project. Franson Civil Engineers provided on-site construction review to ensure the project was constructed according to design.

CONCLUSION

The Red Bridge Water Reuse Project has developed an additional water supply of approximately 10 cfs by constructing a pump station, pond, pipeline, and diversion structure on Spring Creek. The structures allow SHLCC to put to beneficial use, return flows that they own in Spring Creek. The water, which is primarily return flows from Strawberry Valley Project lands, is delivered to Laterals 20 and 20S of the Strawberry High Line Canal System. These lands previously had a limited water supply, and are now able to receive a full supply. By supplying water to Lateral 20, some water can now be exchanged to municipal users for their secondary water systems within the project area, such as Payson and Spring Creek.

The main goal of the project was to apply the reuse water owned by SHLCC in Spring Creek, and to supplement the water supply to shareholders located on Laterals 20 and 20S. This project achieved that goal. The goal was realized through the creative thinking, problem solving, and coordination efforts of all parties involved.

As funds become available, actuators should be installed on the diversion structure control gates. A SCADA system needs to be installed to operate the actuators and pumps. It could also be used to take flow measurements of the water flowing into the pond and measure the flow in the pipeline.

ACKNOWLEDGEMENTS

We would like to take this opportunity to thank the United States Bureau of Reclamation for their $260,000 contribution to this project. Without this contribution, the project would not have been possible. We would like to thank the Strawberry High Line Canal Company board and Mr. Gerald Finch for his cooperation and willingness to sell a portion of his property.

RICE EVAPOTRANSPIRATION ESTIMATES AND CROP COEFFICIENTS IN GLENN-COLUSA IRRIGATION DISTRICT, SACRAMENTO VALLEY, CALIFORNIA

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Thad Bettner[3]
Bryan Thoreson[4]
Richard Snyder[5]

ABSTRACT

The Surface Energy Balance Algorithm for Land (SEBAL®) was applied to estimate remotely sensed evapotranspiration (ET) in the Sacramento Valley (California) for the 2001 crop growing season. The ET estimated by SEBAL was compared to ground-based Surface Renewal ET estimates for a rice field near Nicolaus at daily, monthly and seasonal time scales. For June through September (the period of coincident ET estimates), the SEBAL ET estimate of 33.0 inches was 5 percent more than the Surface Renewal estimate of 31.4 inches. The April 1 through September 30 rice ET estimated by SEBAL was 42.9 inches for this field.

Additionally, district-wide rice crop coefficients were developed for Glenn-Colusa Irrigation District (GCID). GCID is the largest irrigation district in the Sacramento Valley, serving 138,800 irrigated acres. The primary crop grown in GCID is rice. The SEBAL ET results for rice fields in GCID were used to compute average crop coefficient values for each image date and for the months of April through September for the 2001 growing season. The crop coefficients developed from remotely sensed ET were compared to published crop coefficients for rice ET. For the 2,060 rice fields identified for the crop coefficient analysis, the average full April 1 through September 30 rice ET estimate by SEBAL was 39.0 inches.

INTRODUCTION

Satellite based remote sensing techniques have been employed to monitor vegetative growth and to estimate evapotranspiration (ET) for well over two decades (Seguin et. al., 1983, 1989 & 1991). Remote sensing techniques are useful for the estimation of crop ET on a regional scale, particularly when minimal ground-based data such as cropping records are available. Additionally, with the availability of well over twenty years of Landsat imagery, ET can be estimated retrospectively over a range of water supply and cropping conditions. This information can provide useful insights into changes in

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consumptive use relative to urbanization and other factors and aids in modeling of future changes in demands for surface and ground water supplies.

One of the earliest and most thoroughly validated models in the field of remote sensing for estimation of ET is the Surface Energy Balance Algorithm for Land (SEBAL®). SEBAL is a remote sensing based model which applies energy balance physics to estimate actual ET (ET_a) using satellite imagery and ground-based weather data (Bastiaanssen et al.,1998a and 1998b). SEBAL® has been used widely to estimate ET at field and regional scales for multiple crops and land use types (Bastiaanssen, et. al., 2005). Recently, SEBAL has been also used to generate near-real time weekly ET, crop coefficient, and biomass production estimates for the California's Central Valley (Lal, et. al., 2010). SEBAL ET estimates have been compared to and validated by reliable ground-based ET estimates from various methods including eddy covariance, lysimeter, water balance, and surface renewal techniques. These validations have shown that estimates of ET from SEBAL, when applied by an experienced energy balance specialist, typically agree within 5 percent of reliable ground-based ET estimates over the course of a growing season (Bastiaanssen, et. al., 2005).

This paper presents results from an application of SEBAL to estimate ET in the Sacramento Valley of California for the 2001 crop growing season. First, ET estimates obtained from SEBAL for a rice field in the Valley are compared with concurrent ground-based ET estimates from the Surface Renewal (SR) method. Then, crop coefficients developed from the 2001 SEBAL results for approximately 90,000 acres of rice grown in the Glenn-Colusa Irrigation District (GCID) are presented and compared with published values. GCID is the Sacramento Valley's largest agricultural water purveyor, serving a total of 138,800 irrigated acres. Rice in GCID is typically planted in early May and harvested in late September, representing an irrigation season of approximately 150 days.

METHODOLOGY

SEBAL Model

A detailed explanation of the SEBAL model, its applications and validations can be found in Bastiaanssen et al. (2005). A brief conceptual summary is provided herein. SEBAL is a remote sensing model that applies the energy balance at the Earth's surface to estimate actual ET. The energy balance at the Earth's surface is described by:

$$R_n = H + G + LE \qquad (1)$$

Where R_n is the net solar radiation available to drive ET, G is the soil heat flux, H is the sensible heat flux, and LE is the latent heat flux.

In SEBAL, the net radiation flux (R_n) is estimated from incoming solar radiation, after accounting for various gains and losses in short and long wave radiation in the atmosphere and at the Earth's surface. The soil heat flux is estimated as a function of R_n, surface temperature and the Normalized Difference Vegetation Index (NDVI), which provides a relative measure of the amount of vegetation cover present. The sensible heat flux (H) in SEBAL is estimated using a unique 'internal calibration' procedure. H is first estimated at two extremes and is then scaled between these two extreme temperatures for all pixels within the satellite image. For accurate results, the two extremes, termed "hot" and "cold" pixels, must be selected by an experienced energy balance specialist.

The latent heat flux (LE), which is the amount of R_n consumed to vaporize available water as ET, is estimated as a residual of the energy balance based on the principle that energy can neither be created nor destroyed. The latent heat flux is converted into an equivalent depth of water consumed during the process of evapotranspiration using the following relation:

$$ET_a = \frac{1}{\lambda \rho_w}\left[R_n - (G + H)\right], \tag{2}$$

where ET_a is the actual evapotranspiration at the instant of satellite overpass, λ is the latent heat of vaporization of water, and ρ_w is the density of water.

Instantaneous ET_a is extrapolated to daily and longer periods by combining spatially distributed weather conditions from ground-based meteorological stations, evaporative fraction ($\Lambda = \frac{LE}{R_n - G}$), and net available energy ($R_n - G$).

SEBAL Application: Sacramento Valley, CA

A total of eight Landsat 7 ETM+ images (Path 44, Row 33) along with meteorological and ancillary data were processed using SEBAL to estimate remotely sensed actual ET in the Sacramento Valley for the 2001 irrigation season. ET_a from SEBAL was obtained at three time scales: (1) for the day of the Landsat image, (2) for the monthly or semi-monthly period represented by an individual image, and (3) for the accumulated irrigation season from April 1 to September 30, 2001. The specific image dates and periods represented by the individual images are provided in Table 1.

Table 1. Satellite Image Dates for 2001 and Periods Represented

Image Date	Period	No. of Days
April 23rd	April 1 – 30	30
May 25th	May 1 – 31	31
June 10th	June 1 – 30	30
July 12th	July 1 – 15	15
July 28th	July 16 – 31	16
August 13th	August 1 –15	15
August 29th	August 16 – 31	16
September 14th	September 1 – 30	30

Surface Renewal Estimate of Rice Evapotranspiration

A detailed description of the surface renewal techniques of estimating ET can be found in Paw et al. (1995) and Snyder et al. (1996, 1997). Briefly, SR estimates sensible heat flux from high frequency air temperature measurements taken at known heights within the canopy using exposed and naturally-ventilated fine wired thermocouples. The SR methodology is based on the theory that heat transfer takes place when an air parcel from the above comes into contact with the canopy and following the heat exchange, it gets replaced or ‘renewed’ by another air parcel. The increase or decrease in the temperature of these individual air parcels during the heat exchange with the canopy provides the measure of sensible heat transferred to or from the canopy. The sensible heat flux estimates from Surface Renewal are then used with the net radiation and soil heat flux estimates to calculate the latent heat flux or actual ET through closure of the energy balance. The rice field studied is located approximately 3.5 miles southeast of Nicolaus in Sutter County, California and is approximately 140 acres in size (Figure 1).

SEBAL and Surface Renewal ET Comparison

ET estimated by SEBAL was compared to the ET estimated by the SR method for the rice field near Nicolaus at daily, monthly or semi-monthly, and seasonal time scales for the 2001 growing season.

SEBAL ET estimates for the field, were determined for a polygon that was digitized using high resolution imagery representing the approximate boundary of the field, and buffered inward by 30 meters to avoid the potential effects of satellite image pixels overlapping the field boundary. Mean SEBAL ET values were extracted from the rice field at daily, period and seasonal time scales to compare with concurrent SR ET estimates.

Remotely Sensed Lumped Crop Coefficeints (K_{cs})

Remotely sensed lumped crop coefficients (K_{cs}) were developed for the rice grown in Glenn-Colusa Irrigation District (GCID). The lumped crop coefficient is equivalent to a standard published crop coefficient, such as the single crop coefficient (K_c) presented in FAO Irrigation and Drainage Paper No. 56, multiplied by a stress coefficient (K_s), which incorporates various reductions in ET that occur under actual growing conditions.
The remotely sensed crop coefficients for rice grown within GCID were calculated as follows (Equation 3):

$$K_{cs} = \frac{ET_a}{ET_o}, \qquad (3)$$

where ET_o is the reference ET, and ET_a is the actual ET estimated by SEBAL. The reference ET (ET_o) estimates were obtained from quality controlled weather data from a California Irrigation Management Information System (CIMIS) station at Orland.

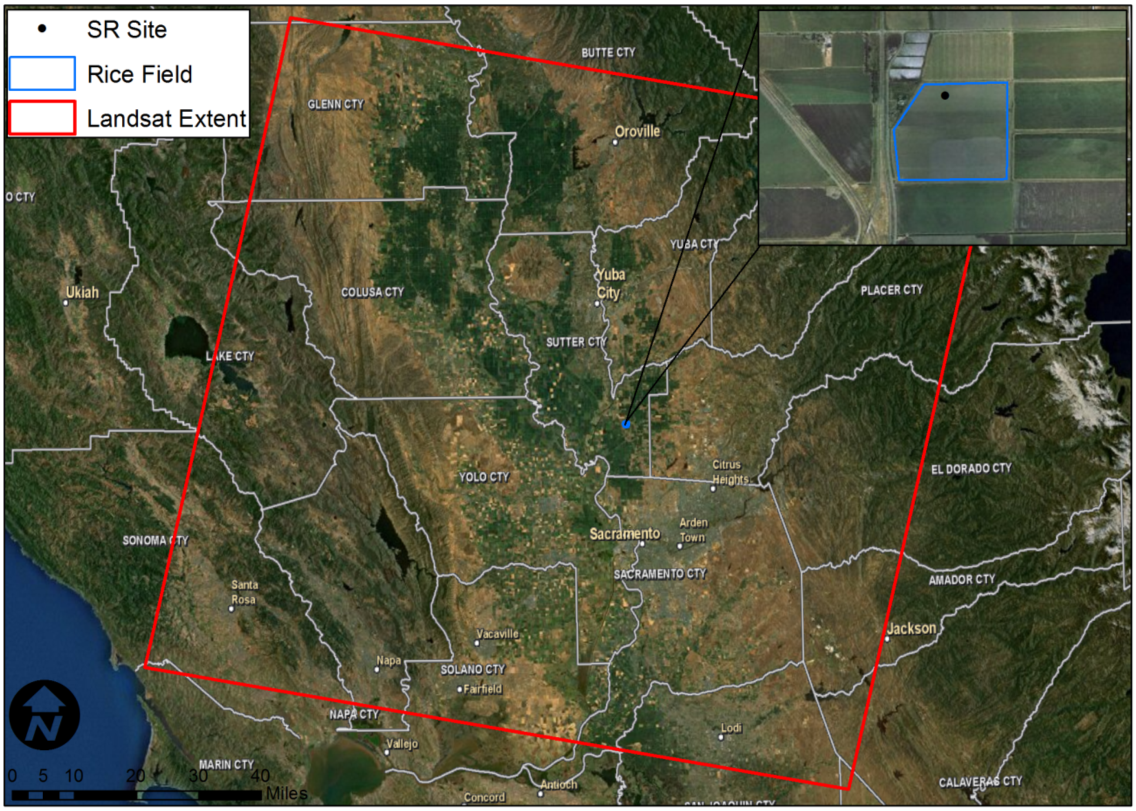

Figure 1. Landsat Image Extent (Path 44, Row 33) and Location of Rice Field for Surface Renewal Comparison

The rice fields within GCID were identified using a GIS coverage of field polygons developed by GCID and linked to the District's 2001 tabular cropping data. In total, 2,060 rice fields encompassing 87,828 acres were identified based on the GCID cropping data.

Prior to extracting ET_a for individual rice fields, the field boundaries were buffered inward by 30 meters to reduce the risk of ET_a for a given field being influenced by ET_a from the neighboring surfaces outside of the field due to satellite image pixels overlapping the field boundary.

Daily SEBAL ET_a estimates for each field were divided by reference ET (ET_o) from CIMIS on a field by field basis to yield a lumped crop coefficient, K_{cs} on the images dates. Additionally, average monthly rice K_{cs} values for the 2001 irrigation season were calculated based on monthly SEBAL ET estimates and cumulative ET_o for the respective months.

RESULTS AND DISCUSSION

<u>SEBAL and Surface Renewal ET Comparison</u>

ET_a estimates for the Nicolaus rice field from SR and SEBAL were compared for the full period of coincident data (May 16 through September 30, 2001), individual satellite image dates, and for periods represented by each satellite image. Daily SR ET data were available from May 16 to September 30, 2001. Daily ET estimates from SEBAL were available for individual satellite overpass dates for which SEBAL was applied as well as for months represented by each image.

The SR estimate of rice ET for June 1 through September 30, 2001 was 798 mm (31.4 inches) compared to 838 mm (33.0 inches) estimated by SEBAL (Figure 2). This 5 percent difference in ET between SEBAL and SR method is similar to differences seen for seasonal ET estimates in other SEBAL applications with reliable ground-based data (Bastiaanssen et al., 2005). This close agreement is important as many uses of ET estimates focus primarily on total seasonal volume.

The SEBAL daily ET_a estimates agree closely with the SR estimates for the main part of the irrigation season (Figure 3). The SEBAL daily ETa estimate for the May 25 image date is 10 to 15 percent less than the SR estimate. The SR equipment started collecting data on May 16th; thus, SR data is not available for comparison to the April 23 image date.

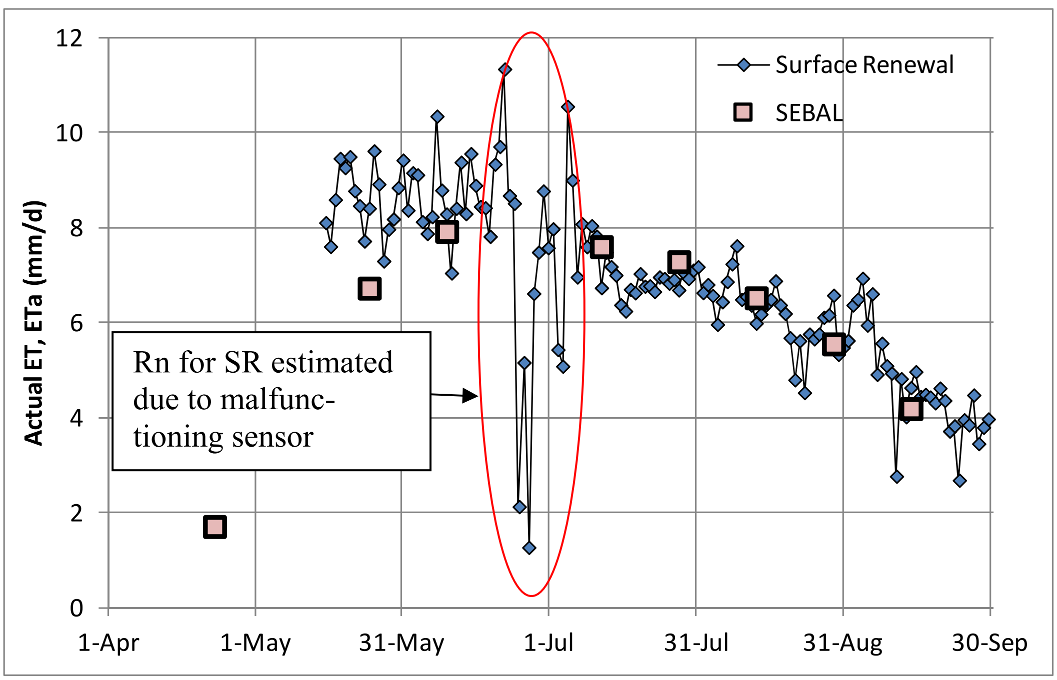

Figure 2. Daily Surface Renewal and SEBAL ET_a Estimates for Study Rice Field, 2001

Figure 3 and Table 2 provide the SEBAL and SR ET comparison for selected individual months for the rice field. This comparison was made only for June - September where SR ET data was available for the entire length of each individual month. April and May were excluded in the monthly ET comparison since the SR ET measurements began on May 16th. The absolute differences between monthly SEBAL and concurrent SR ET estimates ET varied from 6 - 20 percent with an average difference of 13 percent across the four months compared. The overall average 13 percent difference between SEBAL and SR monthly ET is consistent with past comparisons of SEBAL ET_a estimates on a monthly

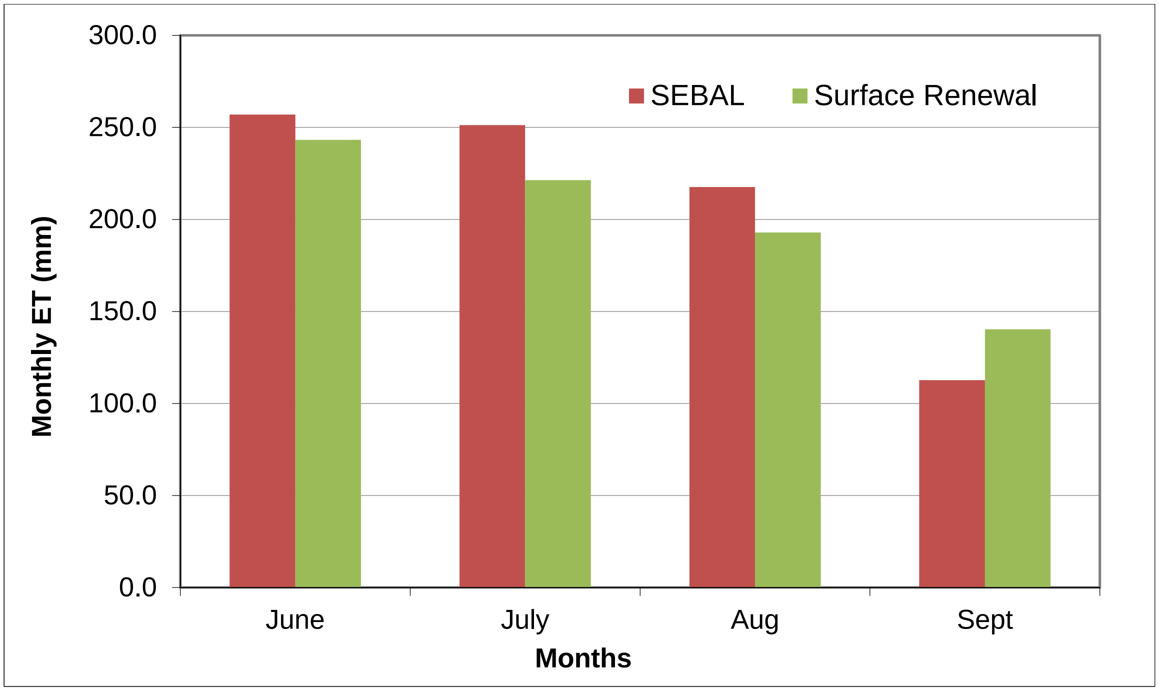

Figure 3. Monthly SEBAL and Surface Renewal ET comparison for the Rice Field

Table 2. Monthly SEBAL and Surface Renewal ET Estimates

Months	SEBAL ET (mm)	SR ET (mm)	Difference
June	256.9	243.2	6%
July	251.2	221.3	14%
August	217.6	192.9	13%
September	112.7	140.3	-20%

basis to reliable ground-based estimates where an average deviation of up to 20 percent was found when SEBAL ET estimates for individual periods/months were compared with the concurrent ground-based ET estimates (Bastiaanssen et al., 2005).

The full growing season rice ET estimated by SEBAL was 42.9 inches, or 3.57 acre-feet per acre, for this field. For the 2,060 rice fields identified for the subsequent crop coefficient analysis, the average full April 1 through September 30 rice ET estimate by SEBAL was 39.0 inches. Ninety percent of the rice fields in GCID had a full season rice ETa between 35.0 and 42.6 inches (Figure 4). This relatively uniform ET_a is indicative of the relatively uniform crop season timing, water supply reliability, and equitable distribution of that water supply throughout GCID. The SEBAL and Surface Renewal estimates of rice ET, or consumptive water use, do not include water that may be required for cultural practices.

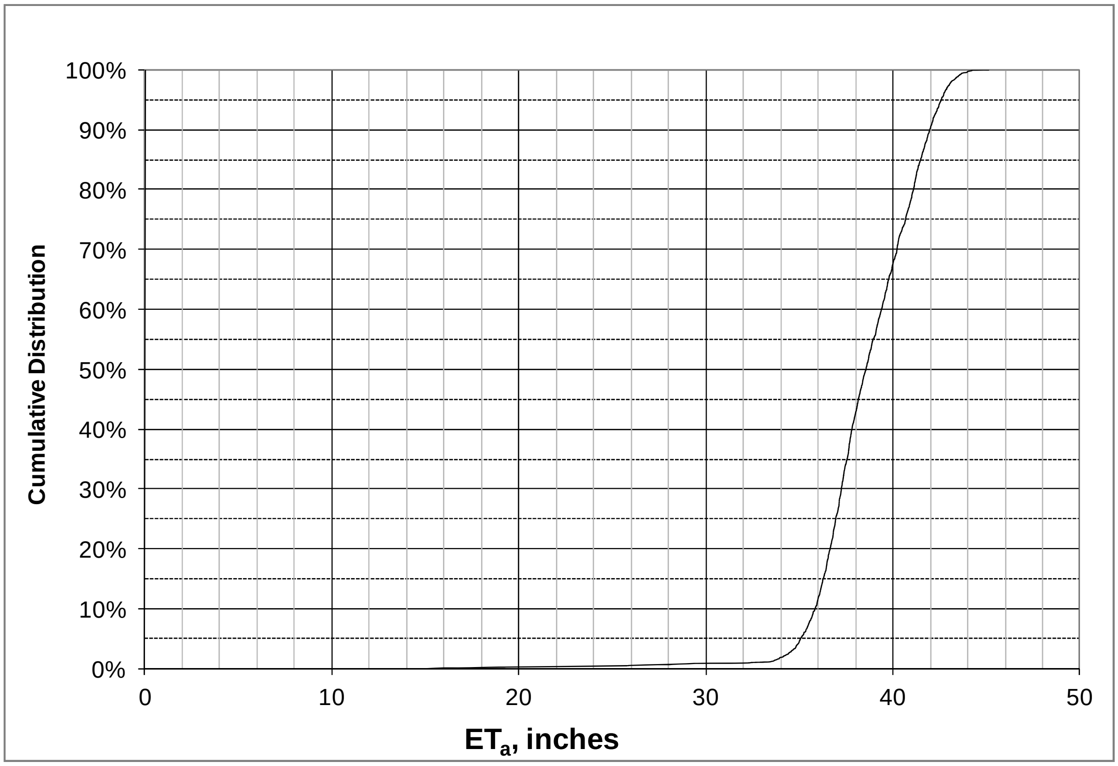

Figure 4. Cumulative Distribution of Seasonal (April – September) ET_a for 2060 Rice Fields in GCID

Remotely Sensed Lumped Crop Coefficeints (K_{cs}) for Rice Fields in GCID

The mean, 10^{th} and 90^{th} percentiles of K_{cs} for all the 2,060 rice fields identified within GCID are shown in Figure 5 for each satellite image date. Additionally, the relative frequency distribution of the field average K_{cs} values on each individual day is shown. A smoothed K_{cs} function based on the Surface Renewal estimates of the single field near Nicolaus generally falls within the frequency distribution of the SEBAL field average K_{cs} values.

Wide variability, particularly early and late in the season is apparent in the K_{cs} distribution for the selected rice fields. The greatest variability in K_{cs} distributions across all the image dates was observed in the April 23^{rd} image (standard deviation of 0.48, Table 3). The relative frequency distribution of K_{cs} on April 23^{rd} suggests that not all the rice fields were flooded by this date. This resulted in a bi-modal distribution of K_{cs} values, with non-flooded fields having K_{cs} in the 0.0 to 0.4 range, and the flooded fields having K_{cs} in the 1.2 to 1.4 range.

A steep increase in K_{cs} is apparent between April 23^{rd} and June 10^{th} during which the average K_{cs} changes from approximately 0.5 to 1.23 reflecting flooding of those fields not flooded by April 23^{rd} and the rapid growth of rice.

In addition to K_{cs} developed for the individual image dates, monthly Kcs values were also developed for the selected rice fields by dividing individual SEBAL monthly ET_a

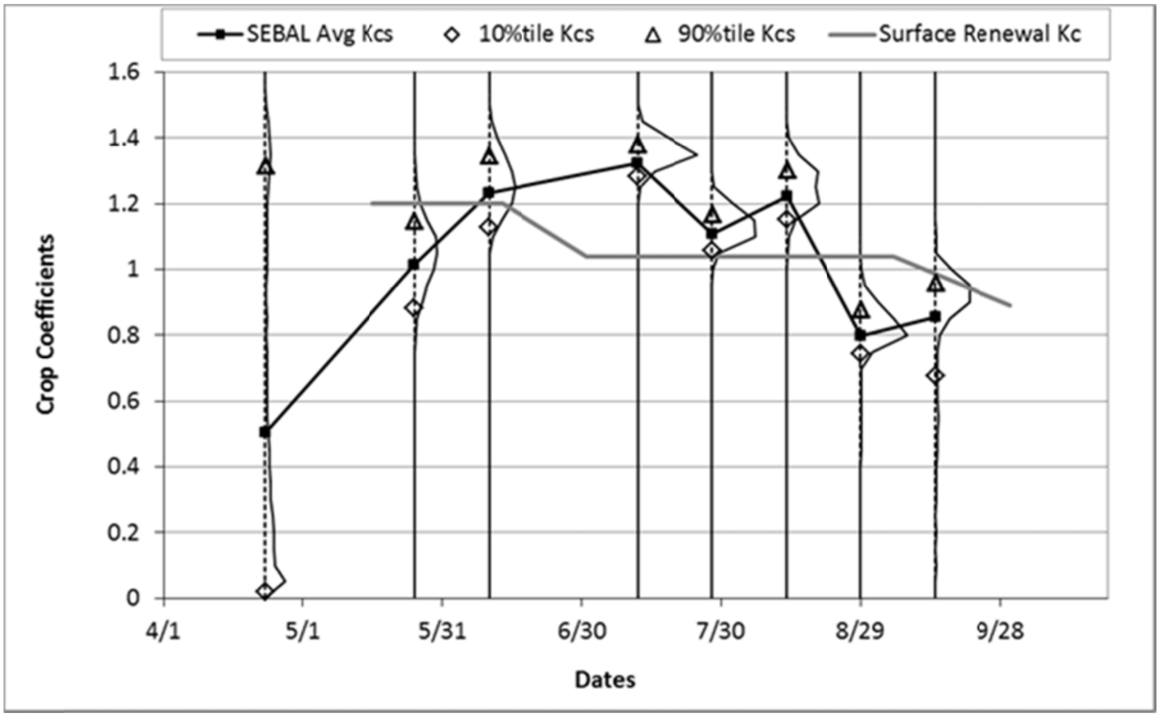

Figure 5. Daily Crop Coefficient Distribution for GCID Rice

Table 3. Summary Statistics of Lumped Crop Coefficient (Kcs) for 2,060 Rice Fields within GCID

Image Dates	10%tile	Mean	90%tile	Std. Dev.
23-Apr-01	0.02	0.50	1.32	0.48
25-May-01	0.88	1.01	1.15	0.14
10-Jun-01	1.13	1.23	1.35	0.09
12-Jul-01	1.29	1.32	1.38	0.10
28-Jul-01	1.06	1.11	1.17	0.07
13-Aug-01	1.15	1.22	1.30	0.08
29-Aug-01	0.74	0.80	0.88	0.06
14-Sep-01	0.68	0.86	0.96	0.13

estimates with monthly ET_o from CIMIS (Figure 6 and Table 4). Monthly K_{cs} estimates are useful in water balance studies performed on a monthly time step and are less impacted by diurnal changes and possible inaccuracies in ET_a and/or ET_o estimates that may occur on a given day. In certain cases diurnal changes and/or inaccuracies in ET_a or ET_o on a given day may result in dramatic changes in the subsequent daily K_{cs} that may not necessarily represent the actual water use trends for the given crop.

The monthly K_{cs} values estimated for rice were compared with the crop coefficient (K_c) values provided in University of California Cooperative Extension Leaflet 21427 (UCCE, 1998) for rice grown in Sacramento Valley (Figure 6). Additionally, K_{cs} estimates (mean, 10^{th} and 90^{th} percentiles) on the individual satellite image dates are included in the figure.

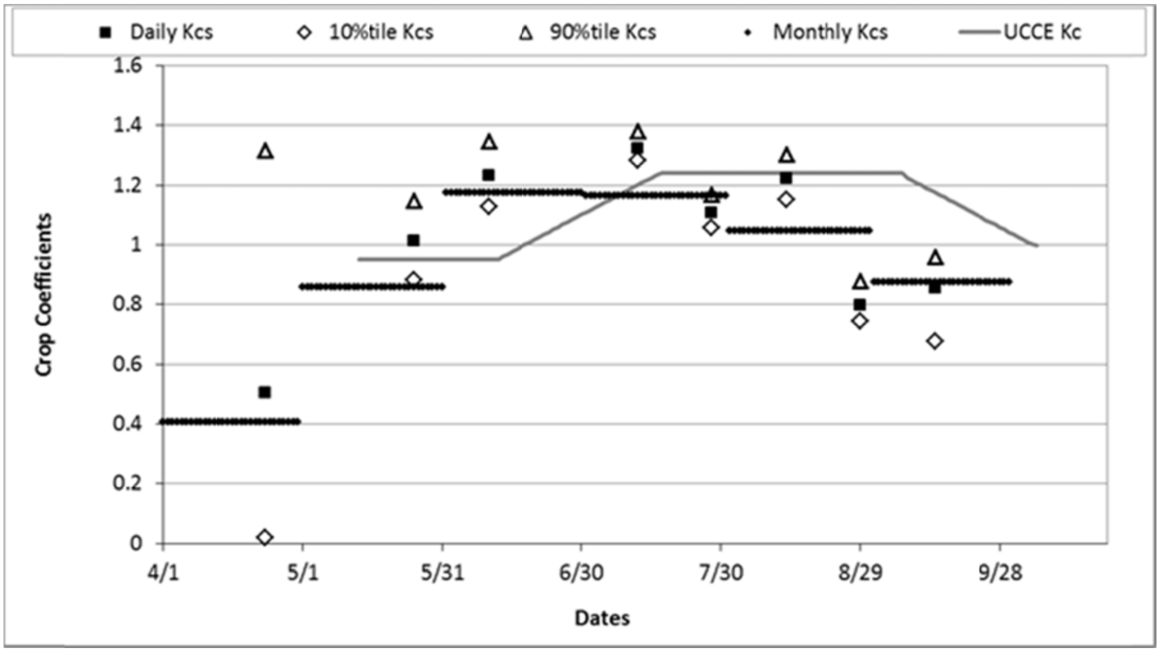

Figure 6. Daily and Monthly Crop Coefficients for Rice

Table 4. Monthly Lumped Crop Coefficients

Months	April	May	June	July	August	September
Average Kcs	0.40	0.86	1.17	1.16	1.04	0.87

The K_{cs} values developed for individual months are generally lower than the K_c values reported 23 years ago by UCCE for the various growth stages of rice. The UCCE crop coefficients were developed for the rice varieties in use at that time and should be updated for more modern varieties. The average Kcs of 0.86 estimated for May is less than the reported Kc value of 0.95 for the initial growth period of rice. The mid-season K_{cs} values of 1.17 and 1.16 for the months of June and July respectively were also lower that reported K_c value of 1.24. Additionally, K_{cs} of 0.87 for September was lower than the K_c of 1.0 reported for the late season.

The differences between estimated and reported crop coefficients for rice may be attributed to differences between actual field conditions and ideal conditions for which the standard K_c values were developed, different rice varieties and different growing season lengths. Additionally, differences early in the season may occur due to differences in the timing of the initial flooding of the rice fields early in the season for a given year relative to the conditions for which the published K_c values were delveloped. Finally, differences between K_{cs} values estimated for this study and K_c values reported in previous studies could be due to differences in the estimation of ET_o from which the crop coefficients are calculated.

SUMMARY AND CONCLUSIONS

The overall objective of this paper was to compare remotely sensed SEBAL ET estimates to ET estimated by the SR method for a rice field. Additionally, the full season ET of rice for the field with the SR equipment and the fields for which crop coefficients were developed are reported. Remotely sensed crop coefficients were developed for rice grown in GCID for the individual image dates and months of the 2001 growing season.

The SEBAL and SR cumulative ET estimates for June 1 to September 30, 2001 were 838 (33.0 inches) and 798 (31.4 inches) millimeters respectively with a difference 5 percent for the four month period. The 5 percent difference between the seasonal SEBAL and SR ET estimates provides a validation of SEBAL at field level for rice based on reliable ground-based data. The absolute difference between SEBAL and SR ET for the individual months (June – September) ranged from six percent to minus 20 percent with an average absolute difference of 13 percent across all the four months. The full growing season rice ET estimated by SEBAL was 42.9 inches, or 3.57 acre-feet per acre, for this field.

For the 2,060 rice fields identified for the subsequent crop coefficient analysis, the average full April 1 through September 30 rice ET estimate by SEBAL was 39.0 inches. Ninety percent of the rice fields in GCID had a full season rice ETa between 35.0 and 42.6 inches. The SEBAL and Surface Renewal estimates of rice ET, or consumptive water use, do not include water that may be required for cultural practices.

Remotely sensed crop coefficients were developed for rice grown in GCID. Wide variability in K_{cs} was observed early and late in the growing season. This variability may result from a variety of factors, including differences in the timing of flooding during the pre-planting preparations, crop physiological responses among rice varieties, or other management related factors. Differences between remotely sensed crop coefficients and published value likely result from differences between conditions for which the published K_c values were developed and actual field conditions for fields evaluated as part of this study.

California is among the major rice producing states in U.S. and more than 95 percent of California's rice is grown in Sacramento Valley. The five percent difference between the SR and SEBAL estimates of seasonal ET_a demonstrates the capability of SEBAL to estimate actual rice ET in the Sacramento Valley, but also suggests that differences between actual field conditions and conditions under which published crop coefficients were developed are substantial and warrant more careful estimation of actual crop coefficients for estimation of rice ET_a in a given year or area. SEBAL ET_a estimates can be utilized to develop remotely-sensed crop coefficients that are more representative of actual growing conditions.

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IMPLEMENTING TOTAL CHANNEL CONTROL® TECHNOLOGY AT OAKDALE IRRIGATION DISTRICT — CASE STUDY

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John Davids, P.E.[2]

ABSTRACT

Oakdale Irrigation District (OID) is a 72,345 acre irrigation district located in both the northeast foothills and valley floor of the San Joaquin Valley of Central California. OID has a 12 year history of marketing conserved water to willing buyers and using that revenue to finance capital improvements. Those revenues are used in a self-perpetuating program to rehabilitate, modernize and further more water conservation in order to generate and market more water. Those efforts have served OID well, generating some $41.2 million in water transfer revenues since 1998.

As its next tier of conservation projects, OID and Rubicon Systems America Inc. (Rubicon) embarked on a demonstration project to bring Total Channel Control® (TCC) Technology to the OID delivery system. The OID system is a 100 year old gravity flow system delivering about 250,000 acre feet per year to a mix of irrigated pasture, almonds, walnuts, rice and both small ranchette and large agricultural field sizes. All these variables lead to difficulty in the efficient management of irrigation water.

To address these issues with modern technology, a $3 million project was agreed upon by Rubicon and OID. The coordinated in-house constructed and managed project involved the replacement of 28 check structures and the design and installation of 31 gates on the 6.5 mile Claribel Lateral and the 8.5 mile Cometa Lateral. The works of improvement were completed during the winter of 2010/2011.

This paper will detail some of the institutional challenges, technological hurdles and construction experiences learned during the implementation of this project.

INTRODUCTION AND BACKGROUND

Overview — Oakdale Irrigation District

In 1909 OID was organized under the California Irrigation District Act by a majority of landowners within the district in order to legally acquire and construct irrigation facilities and distribute irrigation water from the Stanislaus River (ref. Figure 1). 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. Both districts continued to expand their operations over the ensuing decades.

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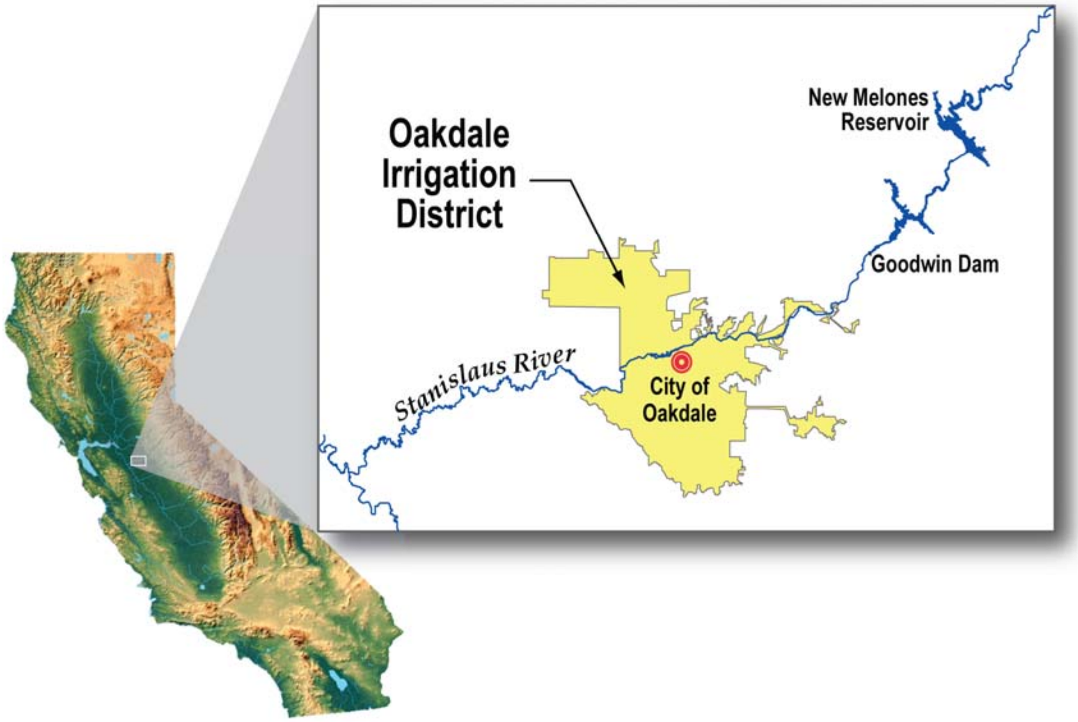

Figure 1. Location of Oakdale Irrigation District

Since their creation, OID and SSJID have constructed dams and reservoirs to regulate surface water storage and deliveries. Most dams were constructed in the 1910s and 1920s, including Goodwin Dam (1913), Rodden Dam (1915), and Melones Dam (1926), which provided 112,500 acre-feet (ac-ft) of shared capacity. To provide supplemental water storage for OID and the SSJID, the Tri-Dam Project was created and built in the 1950s. Tri Dam is a 3-dam network of facilities; Donnells Dam and Beardsley Dam on the Middle Fork of the Stanislaus River, and Tulloch Dam on the main-stem of the Stanislaus River. Hydroelectric generation was also a part of these facilities and today Tri Dam power generation is just over 100 MW per year. This power is sold wholesale on the open market. In total, the three reservoirs comprising the Tri Dam Project provide a storage capacity of 230,400 ac-ft.

In the early 1970s Reclamation replaced the Melones Dam with the larger 2.4 million acre-foot New Melones Dam and Reservoir. The districts have an operations agreement with Reclamation to utilize the federally owned New Melones Reservoir.

These historic and significant capital investments have led to a stable, plentiful water supply for OID. Hydropower revenues have been the main revenue source for day-to-day bill paying. Over the last 50 years, OID has focused its financial resources principally on paying off these capital investments; as a result, OID had invested little in replacement, modernization, automation or rehabilitation of its existing system over the years. That needed to change.

Water Resource Planning

Since its formation on November 1, 1909, OID has watched as water statewide has progressed from being a local resource, fueling the areas' mining and agricultural businesses, to a commodity aggressively sought statewide by municipalities representing millions of people. Wary of these shifting priorities, OID took it upon itself to develop a Water Resources Plan (WRP), a plan focused on protecting OID's water resource over the next 20 years. This two and a half year effort came to an end with the certification and adoption of the WRP in June of 2007.

Key components and the local benefits to be derived from the WRP included;

1. Protection of OID's water rights by defining the uses and purposes of OID's water over the next 20 years.
2. An infrastructure modernization and replacement program that will involve the expenditure of $170 million dollars in construction work to replace, rebuild and modernize OID's water infrastructure.
3. A financial strategy to pay for these improvements with urban water sales and transfers. Thus incurring little or no burden to current customers by way of water rate increases. Keeping water rates low is OID's way of providing our farming community a return on their investment.
4. Protection of the groundwater resources serving the City of Oakdale and local businesses and industries relying on this resource. Good quality drinking water is a priority protection focus in Oakdale.
5. Securing surface water supplies for the Cities of Oakdale and Riverbank should such a demand present itself in the coming years.

The WRP's Overview and Financing

The Preferred Program coming out of the planning process was a roadmap outlining how OID was to meet the long-term rebuilding and modernization needs of the district. Those needs and costs include;

1. Main Canal and Tunnel rehabilitation projects totaling ($44,553,000);
2. Canal and lateral rehabilitation ($24,418,000);
3. Flow control and measurement structures ($13,856,000);
4. New and replacement groundwater wells ($10,460,000);
5. Pipeline replacements ($45,366,000);
6. North Side Regulating Reservoir ($6,264,000);
7. Delivery turnout replacements ($4,680,000);
8. Outflow management projects ($10,947,000);
9. Reclamation projects ($5,813,000); and
10. Miscellaneous in-system improvements ($2,386,000).

In 2007 dollars these improvements represent nearly $169 million over a 20-year window. To finance these improvements the WRP relied on the continuation of revenues derived from water transfers.

Since 1998 OID has had about 41,000 acre-feet committed in water transfer contracts: two to the federal government and one to the Stockton East Water District for delivery of domestic water to the City of Stockton. As mentioned in the abstract, OID has benefited to the tune of $41.2 million in revenues from those transfers. OID has spent all that money on rebuilding and modernizing its water infrastructure to the benefit of the agricultural community it serves. On top of that dollar amount, OID bonded for $32 million in 2009 to pay for some large scale conservation, modernization and rehabilitation projects; bringing OID's total CIP project budget expenditures on infrastructure to over $73 million, about 2/3rds of which was spent from 2007 forward. Based on the WRP's Financial Model, OID needed to continue to invest around $6 million a year in infrastructure to stay current on both lifecycle replacement costs and modernization upgrades.

So in summary; OID sells water to generate revenues to invest in its infrastructure. Those projects result in more conserved water which is then sold again through market transfers in order to generate more revenues to meet the needs of its water delivery system. A simple plan that has brought OID to a decision point on its next level of water management control and conservation; one OID believes can be provided by Rubicon Systems.

THE PROJECT SETTING

OID Setting

OID has a diversion volume off the Stanislaus River for 300,000 acre feet. Since 1998 OID has committed to transferring 41,000 acre feet for municipal and environmental purposes to contracting agencies. The remaining 259,000 acre feet are available to satisfy a crop water demand, a demand in the order of 160,000 acre feet. The difference between the crop water demand and delivered volume of water on an annual basis is lost through operational spills, tail water runoff from farming, deep percolation to groundwater, canal seepage and other less significant losses.

OID's topography varies from gently rolling to the east and south of Oakdale to nearly flat around Riverbank. Approximately 75% of the land within the OID service area consists of irrigated agriculture. The cities occupy about 10% of the balance, the river riparian corridor is about 10% and the remaining 5% has never been plowed or intensively farmed. OID experiences mild, moderately wet winters and warm, dry summers typical of the Central Valley. Average temperatures range from the mid-forties in winter to mid-nineties in summer. Precipitation averages about 12 inches annually, over 85% of which occurs between November and March.

Currently the OID maintains over 330 miles of lateral, pipelines and tunnels, 24 production wells, 42 reclamation pumps to serve local customers. Nearly all canals were constructed in the early 1900's. OID currently serves 2,800 agricultural parcels covering about 57,000 acres. Principle crops are irrigated pasture for cattle, dairies, almonds and walnuts, rice, corn and oats. A driver for the OID is the conversion of about 1,000 acres per year from pasture/corn/oats to nut crops, which once converted, requires a different water demand to meet irrigation needs.

THE DECISION ON AUTOMATION WITH RUBICON

The Rubicon Selection

OID had been a user of the Rubicon FlumeGates™® products for a number of years as it worked its way through various canal gate automation products on the market. The past experience with Rubicon was a beneficial one, not without growing pains as Rubicon evolved their product line, but OID saw a product with potential that shortly matured into a low maintenance, user friendly, accurate flow measurement and control gate.

Total Channel Control® (TCC)

OID had been installing and using the "stand alone" FlumeGates™ from Rubicon at various locations within its canal system for enhanced water control for a number of years. During the initial funding of the WRP it became a focus of OID to replace all its main canal control gates and lateral headings beginning in 2006 with FlumeGates™s. After completing that program in 2009, along with completion of a major regulating reservoir serving farmland on the north side of the Stanislaus River, it was at that point that OID began looking at enhanced flow control within its laterals.

While OID was confident in the stand alone FlumeGates™ it was not aware of the TCC technology provided by Rubicon. In short: TCC provides a high level of water control by using a combination of sophisticated software and control engineering techniques along with wireless communications technology to integrate large networks of remotely controlled, solar powered FlumeGates™.

It was after OID's efforts to automate its main canals and lateral headings that TCC technology came into the picture. Soon after discussions with Rubicon regarding advantages of implementing TCC technology, OID staff visited Australia and more specifically, irrigation districts with the same physical setting as OID, who had implemented TCC. As with most technologies, seeing and talking to water professionals who have a history of use in the practical application of that technology was invaluable.

The major benefit seen by OID was the scalability of the technology provided by Rubicon. From main canal control, to lateral heading control, to pond to pond control within the lateral, to farm gate control at the turnout, to water order entry, tracking and scheduling, to Rubicon's on-farm system monitoring of soil moisture; it is an impressive array of conservation options for an irrigation district.

THE RUBICON PILOT PROJECT

Project Scope

Soon after staff's return from Australia a pilot project proposal was present to the OID Board of Directors for their review. The proposal was to implement a head-to-end installation of Rubicon's Total Channel Control® automation system on two of the OID's key canals, the Claribel Canal on the south side of the river and the Cometa Canal on the north. The project scope included the following;

- Installation of 31 FlumeGates™
- Installation 6 Slip Meters at selected farmer turnouts
- Implementation of SCADAConnect Software
- On-line Water Order Entry/Ordering System
- Related Equipment inclusive of radios, antennas, solar panels, IT/Servers, etc.
- Training and Service Support and Commissioning

Both systems on the Claribel and Cometa were expected to be fully operational for the beginning of the 2011 irrigation season. The system will be evaluated over the next two irrigation seasons to gain operational knowledge prior to expansion throughout the OID delivery system.

The Project Goal

The system will allow OID to better use their water; improving distribution efficiency and enhancing service levels to farmers by providing a near on-demand supply. Farmers will also benefit from consistent flows rates, which the system is able to achieve by closely matching demand and supply. Efficiency improvements afforded by TCC will enable OID to further its ongoing efforts to conserve its water resources.

The Claribel Canal System

The Claribel Canal has a heading capacity of 138 cfs. From its heading-to-spill the canal is 6.5 miles in length. It contains 17 pools along its reach. The system is mostly earth lined with sections of concrete lining and sporadic sections of pipelines.

The Claribel Canal system was chosen to test the ability of TCC in reducing operational spill. Operational spills are an operating inefficiency of open canal systems but are a necessity to insure all water orders are fully filled. The amount of losses at the end of the Claribel ranged from about 1,500-2,000 acre feet per year depending on various factors.

The Cometa Canal System

The Cometa Canal has a heading capacity of 306 cfs. From its heading-to-end the canal is 8.5 miles in length. It contains 13 pools along its reach and is a much flatter system compared to the Claribel System.

The Cometa was chosen in the hopes of improving operational flows to its terminus; the beginning of the Fairbanks Lateral serving another water division. An operational problem is that the upper Cometa flows through and serves another water division of OID and is managed by a different Distribution System Operator (DSO). As human nature is, the upper operator insured his needs were filled and the lower operator was pretty much at his mercy for water; hence a "feast or famine" situation.

PERFORMANCE RESULTS OF THE PROJECT

Claribel Canal Performance

The Claribel System is feed from the Robert Van Lier Regulating Reservoir. The reservoir outlet is controlled by two Rotork Hydraulic Actuators. Integrating the Rotork actuators into the TCC system controls resulted in a delay in fully implementing TCC on the Claribel Canal until late in the water season. This was not a TCC or automation glitch, it was a Rotork hardware system and warranty issue that delayed turning the system over to full automation.

Despite the delay of full automation, partial automation with the limited system had promising results as seen on Figure 2.

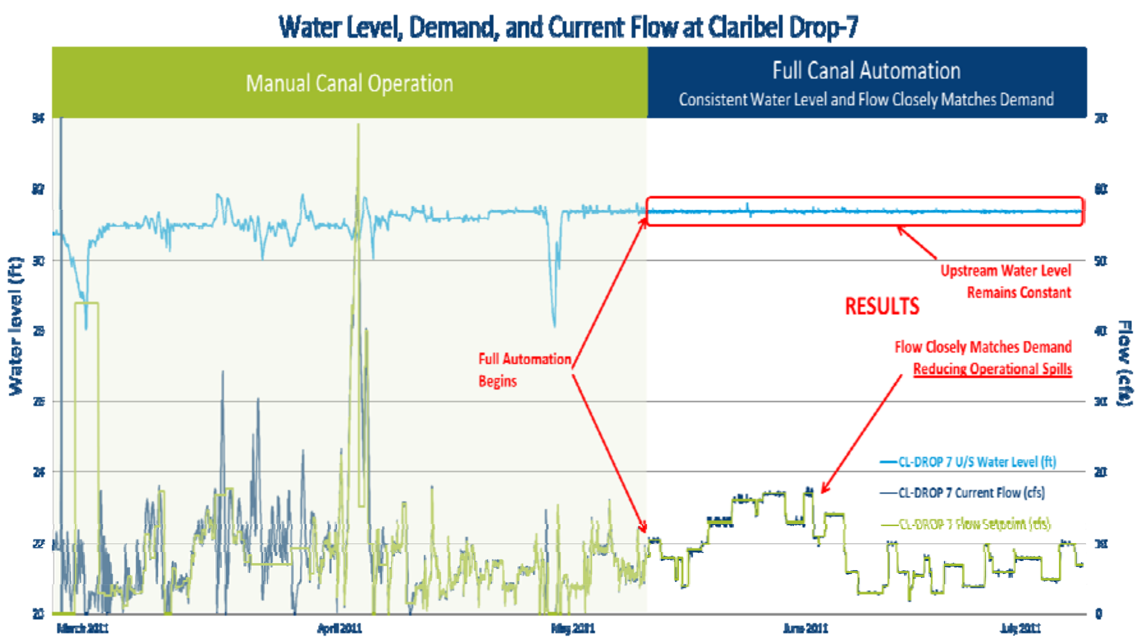

Figure 2. Water Level Demand Results on the Claribel Canal before and after TCC

Claribel Canal Operational Spill Performance

One of the goals was the reduction of operational spills on the Claribel Canal. While not a full year of implementation, for reasons cited, the anticipated benefits are graphically shown on Figure 3.

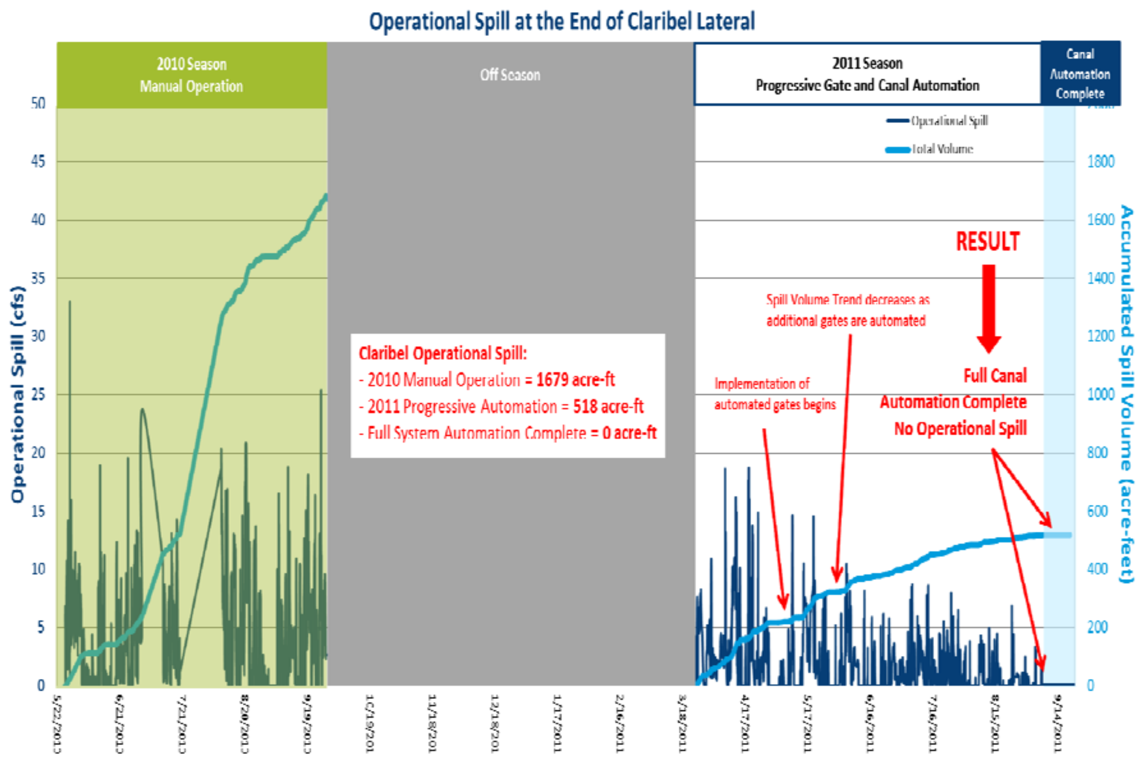

Figure 3. Operational Spill Performance on the Claribel Canal as TCC Implemented

The left side of Figure 3 represents the spill and the variability of that spill as occurred during the 2010 water season without TCC. The right side of Figure 3 presents the decreasing nature of that spill and decreasing variability of spill as TCC was incrementally implemented during the 2011 water season. Even with incremental implementation during the 2011 water season, spill at the end of the Claribel Canal was reduced by 1,160 acre feet. As shown in the light blue at the far right of Figure 3, spill is reduced to zero when TCC is fully implemented on the Claribel Canal at the very end of the 2011 water season.

Cometa Canal Performance

The focus on the Cometa Canal was to enhance flow deliveries to the end and to minimize flow fluctuations to the downstream water division. As can be seen in Figure 4 below, TCC implementation was successful in achieving that result. Statistically, average water level variations on the Cometa Canal improved by 92% to be within +/- 2 inches of the canal's set points for water delivery flows.

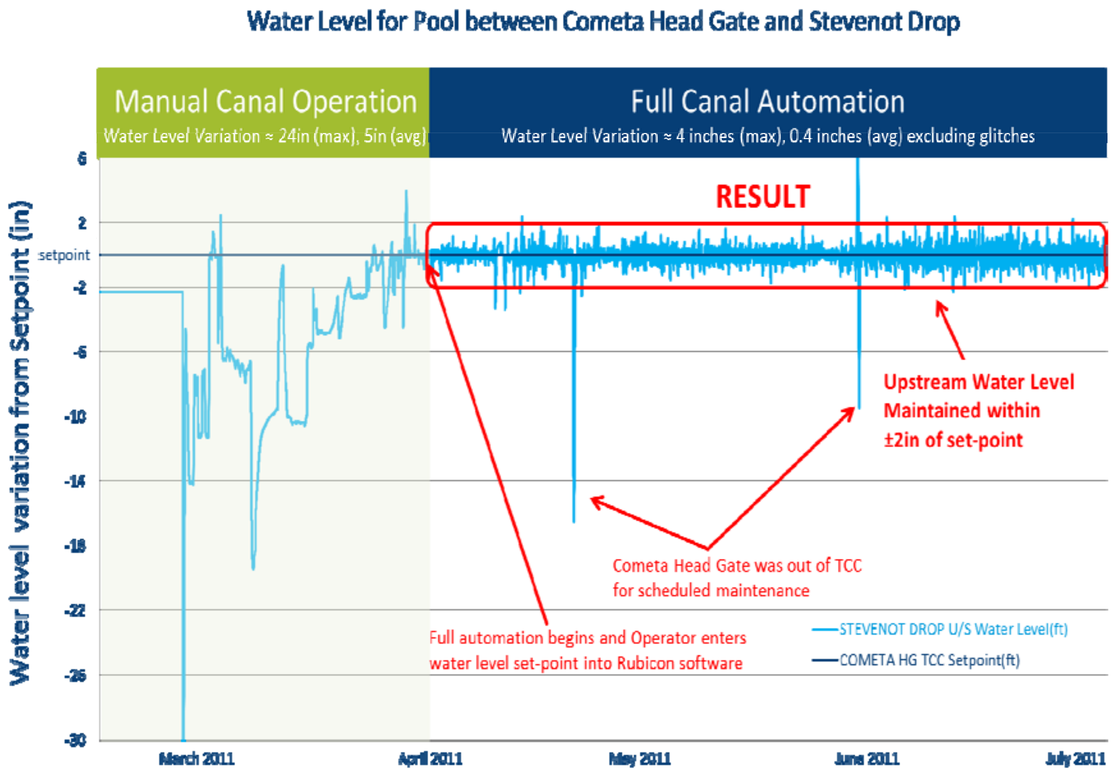

Figure 4. Water Level on the Cometa Canal after TCC Implementation

ANCILLARY BENEFITS OF THE PROJECT

Institutional Betterments and Changes

One of the concerns with implementing new technology is the acceptance of the workforce in operating that technology. Obviously, when ditchtenders went from riding horses to driving vehicles to make water deliveries, there were substantial adjustments required. Going from manually controlled water systems to fully automated systems carries with it similar adjustments and similar concerns. From a management perspective, is the workforce competent or skilled enough to make the transition and from the workforce perspective; are they working themselves out of a job?

Competent Workforce Concerns. OID had water operations employees with little to no computer skills. Many workers did not own personal computers. So the decision to implement a computerized automation system had some reservations concerning workforce acceptance and competency. Early training of a small group of DSO's by Rubicon in setting up the flow networks on the canals proved an ice breaker to the technology.

Similarly, intensive group training, both classroom and hands-on, was part of the delivery package from Rubicon. Whether the DSOs were going to be involved or not with the

Claribel or Cometa systems during the water year, everybody went to training, another good ice breaker.

The real benefit for this early-on worker exposure was the confidence building it provided. Another revelation to the workforce was; the technology was not that difficult. OID workers with little to no previous exposure to computers easily picked up on the simplicity of the software. The ease by which most workers were able to grasp the simplicity of the systems logic was a real plus.

During the water season, OID generally requires its DSOs to stay on their ditches during their shifts. With implementation of TCC on the Claribel and Cometa Canals during the 2011 water season management encouraged DSOs to ride along with those DSOs operating TCC to get a feel for the ease of system controls and to grant greater exposure to this automation. It proved beneficial and management was impressed and somewhat relieved with the breadth of worker adaptability and acceptance of this technology.

Workers Working Themselves Out-of-Work. In management's report back to the Board after its trip to Australia one of the underlying benefits of TCC is the potential reduction in the workforce derived from TCC implementation. What was realized in Australia was the downsizing of 20% (+/-) in the water operations area, not insignificant considering OID's water operations labor budget of $2.4 million. Outside these reductions, a portion of the remaining workforce is absorbed into other job-created benefits of TCC. SCADA technicians, troubleshooters, planners, schedulers, etc. are positions created because of technology, and generally better paying jobs over existing DSO positions.

So while you have some job position losses as a result of automation you also have job position creation as a result of automation, but to the workers, the net loss was a concern. The outright assurance from management that losses, if they occurred, would be through attrition and not layoffs, put most workers at ease. This point was put to rest at a general training meeting of DSOs. Management stated that if TCC were implemented over the next 10 years, and resulted in a net 20% reduction of the DSO workforce, the workforce would be reduced by 5 positions. Management then asked how many workers would be retiring due to age over the next 10 years and 7 DSOs raised their hands. They issue seemed to be resolved, at least temporarily.

COSTS OF TCC IMPLEMENTATION AT OID-PRELIMINARY

Project Budget and Actual Costs

Description	Budgeted Costs	Actual Costs
Rubicon (Gates, Labor, Software, etc.)	$1,702,680	$1,444,005
Surveying and Structural Calcs.	85,000	46,678
OID Material and Equip	500,000	778,392
OID Design, CM, and CM Labor	609,000	630,920
Total 2,896,680		2,899,995

Using these costs and calculating a cost/mile unit rate, the TCC system cost $193,333/mi.

Applying simple Return on Investment (ROI) calculations to the Claribel Canal system, using the range of potential water savings and assuming a reasonable California water transfer rate of $125 per acre foot, the ROI would fall somewhere between 9-11 years. A very noteworthy marketable return.

CONCLUSIONS

Take-aways from Implementation

OID implemented TCC on just 2 canals of a much larger system. It's a two-year study and just one-year has thus been completed. The results and benefits of the project are encouraging and next water season, will hopefully affirm OID's optimism.

Grower/farmer responses who were on the receiving end of TCC were minimal at best and in the irrigation district business, that's a big plus. There were no complaints from users, just casual responses on the improved service standard afforded them. On the DSO/operator side, those who were exposed were impressed. Ease of functionality and the lack of "glitches" were notable.

As with all new technology, some constraints in responsiveness were noted. With OID's small canals and relatively steeper sloped systems, sometimes the response to an order change was not as it would have been if manually operated. While in most cases, this is an adaptable and manageable adjustment, it is being evaluated in the 2012 water season. OID is evaluating the possible need of distributed small scale distributed storage systems to account for this peculiarity as a solution.

Confidence Building of Workforce

Both on the construction side of the TCC project and operations side, OID employees came away with a sense of accomplishment this last water year. Construction crews at OID did a remarkable job in putting these facilities in under the time constraints given. They honed their skill sets and improved upon their scheduling and work coordination abilities to the point that construction costs came in on budget.

Water operations staff learned more about automation, canal control and SCADA systems in one year than they ever imagined they could. Computer skills and technology are now not a foreign thought in the workplace anymore. The exposure and the accomplishments of the DSOs who were over the TCC implementation were impressive to management as well.

OID is very optimistic about Rubicon Systems and the TCC technology that has been implemented. The potential for additional water savings at a marketable rate based on TCC fits OIDs water conservation and marketing prospectus and has great promise for the future.

IMPROVED WATER RESOURCE MANAGEMENT USING AN ACOUSTIC PULSED DOPPLER SENSOR IN A SHALLOW OPEN CHANNEL

Mike Cook[1], PhD
Craig Huhta[2]

ABSTRACT

Over the years, acoustic Doppler profilers (ADP) have become a standard for flow measurement in large open channels. In most cases, pulsed Doppler systems measure the water-velocity profile either from the side of the channel or from a bottom-mounted system. Having a velocity profile is critical in providing accurate flow measurements and provides important information about the structure of the velocities in the flow. These systems are often optimized for different sizes of open channels by using different acoustic frequencies, acoustic beam configurations as well as other factors, however, ADPs have been traditionally too expensive for flow monitoring in small channels. Traditional alternatives to ADP for measurements in small channels have used water level as a surrogate or continuous wave acoustic instruments. These two technologies, although inexpensive, do present problems to end users in the form of accuracy, which can be a major problem when making decisions or billing based on the collected data. Building on the success of ADPs in open channels and considering the increasing demand to quantify flows in very small channels due to the increasing scarcity of water, SonTek developed a shallow water flow meter – the SonTek IQ - for open channels ranging from 0.08 m to 5 meters in depth. The new flow meter uses multiple beams to measure water velocity and applies a vertical beam and pressure sensor to measure water level – these two types of data are used to calculate flow. In addition to the new design, the IQ provides improved performance for theoretical flow calculations, which are important in smaller channels, such as ditches and turnouts where an index calibration may not be practical when considering cost. This paper describes the sensor configuration, preliminary specifications and theoretical flow models used to calculate open channel discharge. Preliminary testing in flow laboratories demonstrated good agreement when compared to independent measurements.

INTRODUCTION

Traditional flow monitoring in open channels has been done by monitoring water level (stage) as a surrogate. For this method, a rating curve is developed by comparing various water levels to the corresponding flows, which are determined by discharge measurements or gagings over a range of water levels and time at the site. Using this method, periodic discharge measurements are required to validate the stage-discharge relationship. For some sites such as tidal rivers and locations with variable backwater like irrigation gate control systems, no reliable stage-discharge relationship is developed. At these sites, a velocity index relationship is typically used. For a velocity index, a channel cross-section survey provides a relationship between stage and cross sectional area. A

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velocity sensor is installed and a relationship is developed between the velocity of the permanently installed sensor and the mean measured velocity in the channel (via gaging). The combination of the stage-area and measured-mean velocity relationships provides the ability to continuously monitor discharge. Like the stage-discharge method, this velocity indexing also requires periodic discharge measurements at the site in order to maintain a viable index, however, using a velocity to determine flow in complex hydrologic conditions are more accurately monitored.

Side-looking Doppler velocity sensors (such as the SonTek Argonaut-SL) have become a preferred method for monitoring velocity at index rated sites in larger channels. The sensor is mounted on a vertical structure and measures a horizontal velocity profile as a programmable cell some distance into the river. Simple installation, low maintenance requirements, and the ability to monitor velocity away from flow interference generated by underwater structures are advantages of these sensors. Side-looking instruments do have some limitations; for instance, the relationship between Doppler velocity (measured at one depth) and mean channel velocity can be difficult to determine in situations of highly variable water level. In addition, sites with highly stratified flow can require permanent installations at more than one depth. Lastly, from a resource standpoint, it is not always practical to make the measurements required to develop an index rating. For side-looking systems, this theoretical relationship is less robust because velocity is measured only at a single depth and stratification of flow in open channels is vertical.

Considering these issues, the Argonaut-SW (SW for “Shallow Water”) was developed. The Argonaut-SW is a bottom-mounted system that is intended for complex index velocity index sites (those with large stage variation or stratified flow) and for sites where purely theoretical discharge calculations are desired. Although very accurate and precise in regular open channels, the SW requires 1-foot (ft) (30 centimeters (cm)) of water depth to measure to measure flow which is not convenient for measuring flow in irrigation applications. Thus small channels and irrigation turnouts have looked to measuring flow using other devices which are limited to determining discharge with techniques that are not accurate or repeatable (measure flow based on water level or determine flow using low cost continuous wave Doppler instruments that do not have a high degree of accuracy or precision). Continuous wave devices obtain an average velocity taken from sampling only a portion of the vertical water column, while profilers, like the SW collect water velocity data as a vertical profile as such are more accurate.

Considering the increasing demand for freshwater resources and the effects of climate change, there is an increased need to quantify flow in smaller and smaller channels, such as irrigations turnouts. In 2007, SonTek was awarded a Small Business Innovation Research (SBIR) grant from the United States Department of Agriculture (USDA). The goal of the project was to develop a Doppler-based instrument that would measure flow in small channels and irrigation turnouts with a minimum depth of 3-inches (in) or 8-cm with a high degree of accuracy – thus end-users are not required to perform a velocity index or calibrate the instrument to the site while still providing an accurate and reliable measurement.

MATERIALS AND METHODS

This paper presents flow comparison study from three irrigations canals using rating data from the USGS or data collected using the FlowTracker. Each canal represents a "typical" irrigation canal. The Overland canal is an earthen channel with vegetation found on the banks; the Overland canal is located in Fort Collins, Colorado. A FlowTracker measurement is used as the reference flow data for the Overland Canal. The Cocopah canal is located near Yuma, Arizona and is a concrete line canal. Reference flow was data collected from the USGS rated ramp flume as well as FlowTracker measurements. The Ypsilanti canal is also located near Yuma, Arizona and is a concrete lined trapezoidal canal that uses data from the FlowTracker and rating data from a broad-crested weir. Figure 1 presents a picture from the installation at the Cocopah canal.

Table 1. Summary of flow comparison sites

Site	Canal Type	Reference data
Overland	Natural canal, earthen lined	FlowTracker
Cocopah	Trapezoidal channel, concrete lined	Rating data and FlowTracker
Ypsilanti	Trapezoidal channel, concrete lined	Rating data and FlowTracker

Figure 1. Cocopah canal flow comparison site

The SonTek IQ was designed to provide highly accurate and precise flow measurement in shallow channels. A built in pressure sensor and vertical acoustic beam are used in tandem to determine water level, while four velocity profiling transducers - two that measure velocities along the channel flow axis while two skew beams measure flow in the horizontal direction. The skew profiling beams measure velocities at 60° off the vertical axis and 60° center axis of flow, while the along axis profiling beams are 25° off of the vertical axis. A drawing of the instrument is presented in Figure 3. The housing of the sensor has screws pre-set in the mounting brackets all of which were designed for an easy install. The instrument was configured to collect data every 30 seconds and average data for 30 seconds – effectively measuring flow continuously. Flow is determined by using a combination of the water level data that are converted into cross-sectional area using the cross sectional area rating. The cross-sectional area is multiplied by average velocity (taken from the averaging interval) to determine flow.

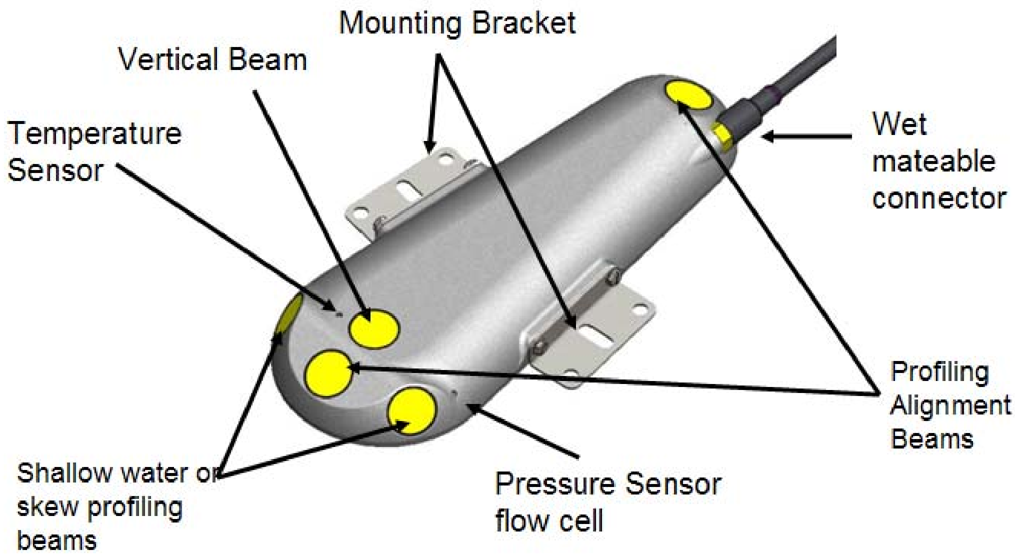

Figure 3. Features of the SonTek IQ

Figure 4 presents a configuration of the IQ for data collection. In order to calculate flow the user has to enter the channel cross-section. System elevation or the elevation of the vertical beam referenced to channel bottom, for this configuration the system elevation is 0.31 ft (effectively the height of the instrument). Figure 4 presents how the instrument was configured using the IQ software. The software is divided into five sections with quality indicators to drive the user to deploy the sensor correctly.

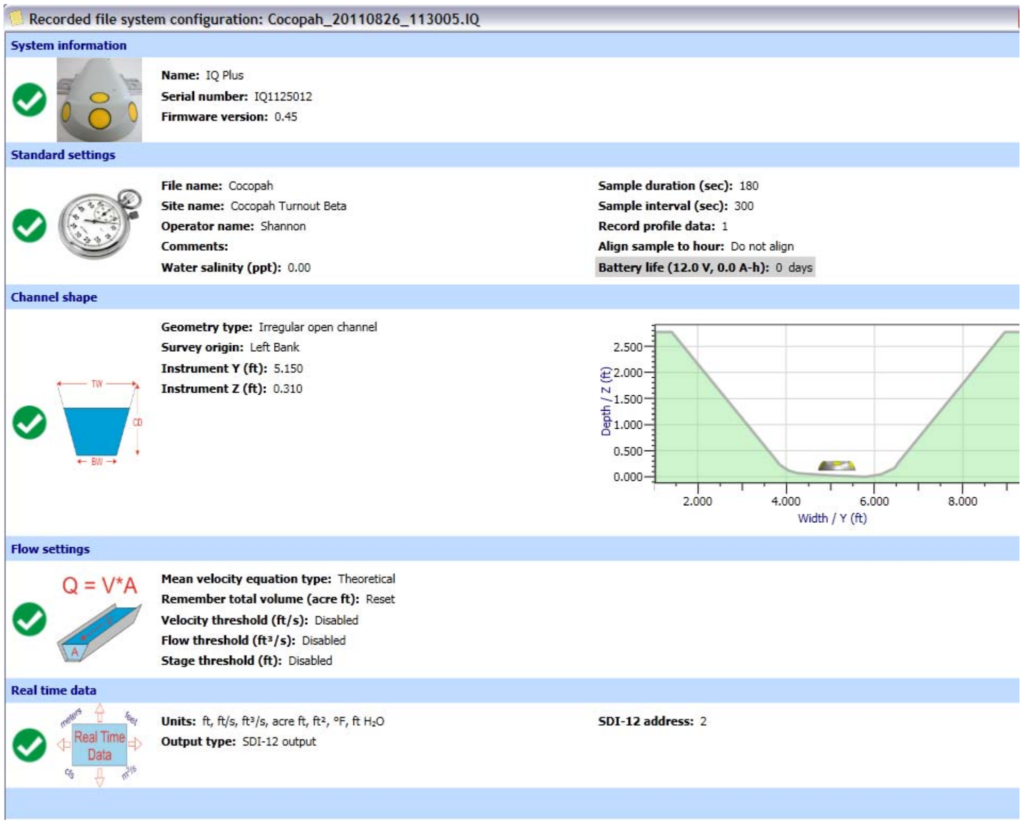

Figure 4. SonTek IQ example configuration

To configure the instrument, the user can define File Name, Site Name and Operator Name, while setting the Sample duration and interval are required. In order to calculate flow, a user defined cross-sectional area must be entered. Lastly, additional settings for managing velocity data and configuring the connection to a datalogger or Modbus system must be completed.

RESULTS

The results from the three tests at the sites are presented in Figures 5 - 7. Each figure presents Flow data in the first graph, water level in the second graph and velocity data in the third time series graph. The graph to the right is profile data collected by the instrument. Black vertical lines indicate where reference measurements were made. In the case of the Overland site, an average of the flow data collected with the IQ was compared to a FlowTracker measurement made over the same period (Figure 5).

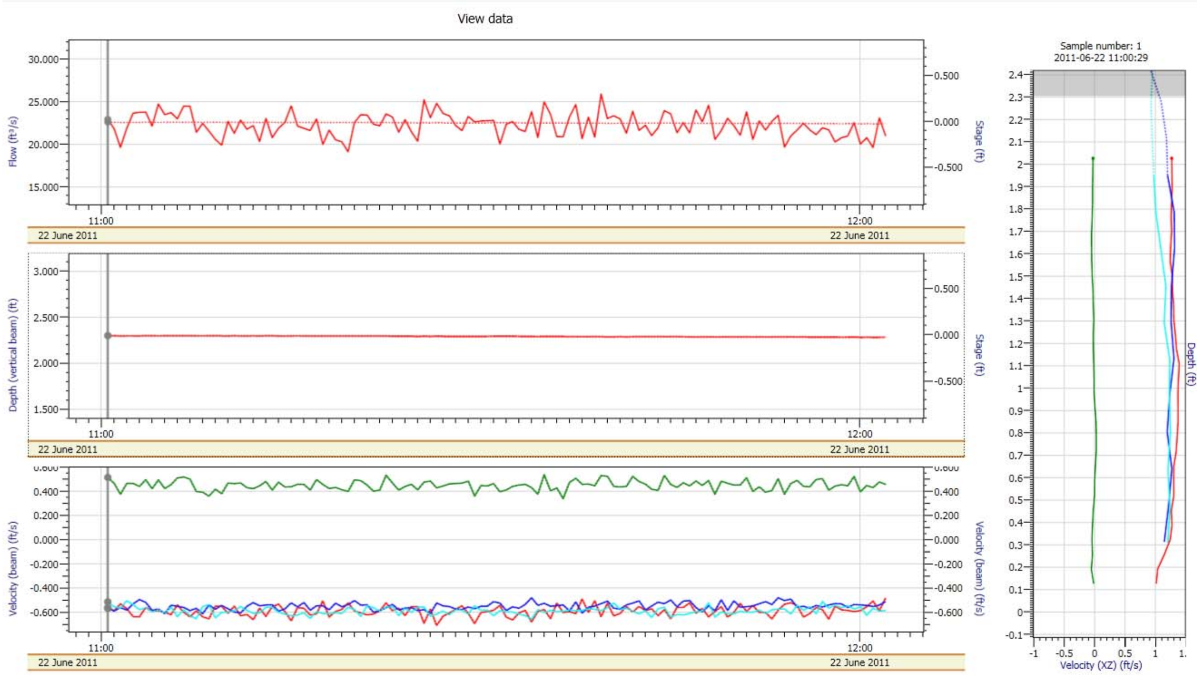

Figure 5. Overland test site with one reference measurement

Table 2 presents the comparison data in table format. The difference between the SonTek IQ flow data and reference data is 1.6%.

Table 2. Summary of comparison flow data at Overland

	Water Level (ft)	IQ Flow (cfs)	Reference (cfs)	% Error
Comparison 1	2.30	22.32	22.68	1.6

Figure 6 presents data collected at the Cocopah site. The site has three comparisons, using data from the FlowTracker and gauging information from the site. Overall, flow data compared well to the reference and data was representative for the site.

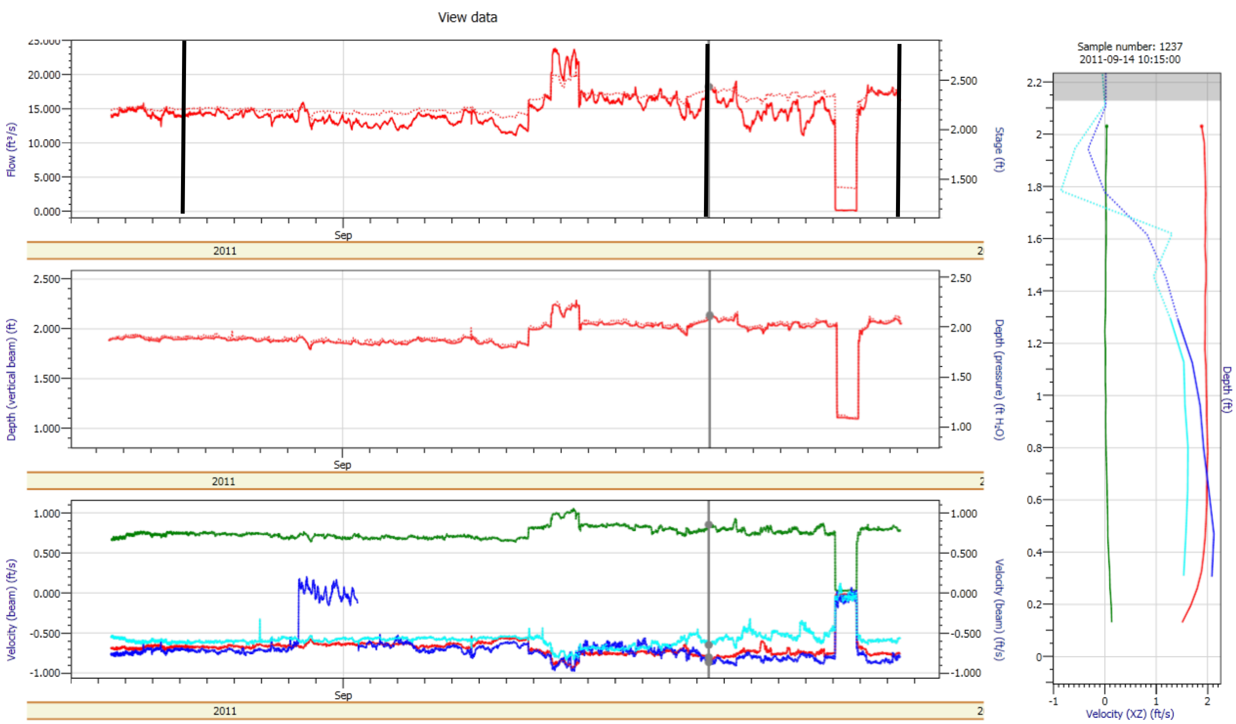

Figure 6. Cocopah test site with three reference measurements

Table 3 presents a summary of the data collected at Cocopah. Average error for the three reference measurements is 2.83%.

Table 3. Summary of comparison flow data at Cocopah

	Water Level (ft)	**IQ Flow (cfs)**	**Reference (cfs)**	**% Error**
Comparison 1	1.89 13.84		13.48† 2.6	
Comparison 2	2.12 17.80		18.49*	-3.7
Comparison 3	2.06 16.48		16.85*	-2.2

† USGS Gauge data
*FlowTracker data

Figure 7 presents data from the Ypsilanti Site. Data from the site was very typical, with varying flow rates stepped up and down for water delivery to farmers. Four comparisons are presented three from gaging data and one from a FlowTracker measurement.

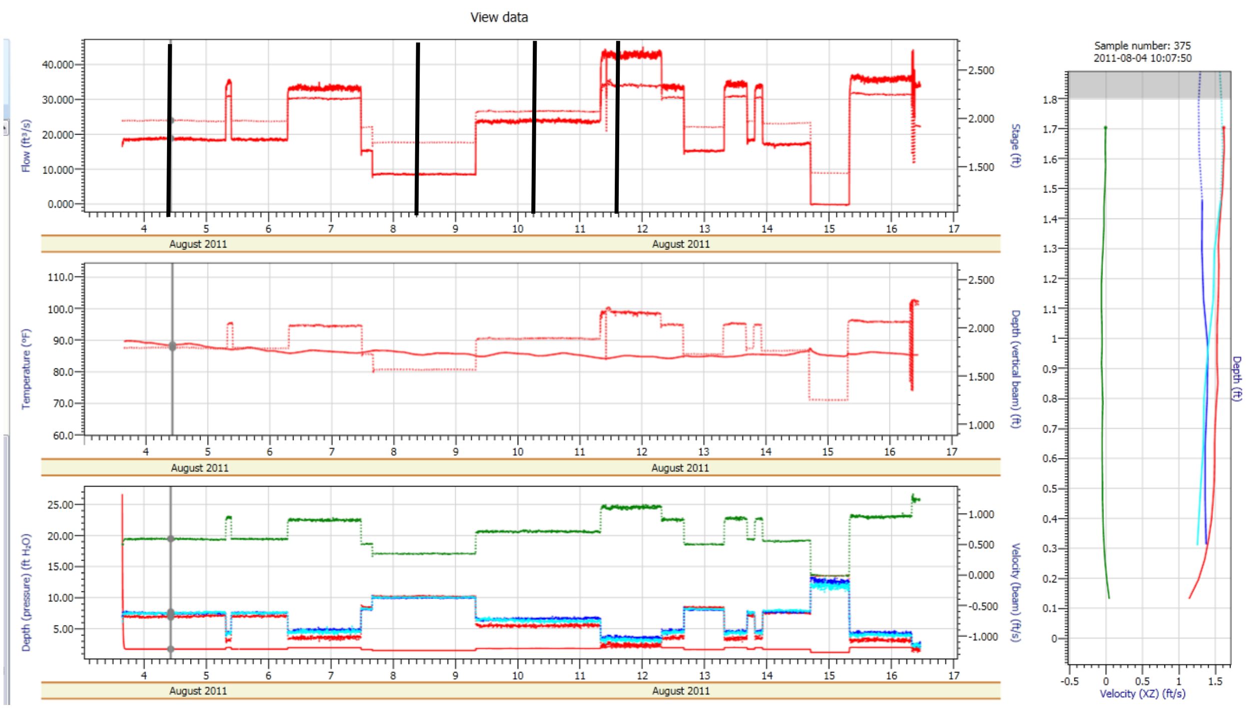

Figure 7. Ypsilanti test site with 3 reference measurements

Table 4 presents the comparison data in tabular form. Overall the data compared well to the reference measurements, with an average error of 1.28%.

Table 4. Summary of comparison flow data at Ypsilanti

	Water Level (ft)	IQ Flow (cfs)	Reference (cfs)	% Error
Comparison 1	1.81	18.73	19.01†	1.0
Comparison 2	1.58	8.36	8.45†	1.4
Comparison 3	1.90	23.85	24.33†	1.6
Comparison 4	2.19 43.7	0	43.25* 1.0	

† USGS Gauge data
*FlowTracker data

CONCLUSIONS

Results are encouraging for the range of flow rates presented here (8-43 cfs) however additional tests should be conducted to verify the performance of the instrument in a wider range of flow conditions as well as verify the accuracy of the reference measurement. Based on these preliminary comparisons, the SonTek IQ measures within 3% of the reference flow measurements. The results were obtained simply by installing the instrument – no site specific calibrations were completed, thus resources were not only saved with the accuracy of the instrument but also for the time and resources to calibrate the instrument. Future tests will incorporate variations in water-level, flow velocity and the corresponding flow rate in conjunction with field testing as well. Field testing for flow rate will be verified by comparing flow rates to reference flows or by making spot measurements using instruments in the field.

ACKNOWLEDGMENTS

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GATE AUTOMATION AND CENTRALIZED CONTROL IN A SOUTH CENTRAL TEXAS IRRIGATION DISTRICT

Stacy Pandey[1]
Brad Funk[2]

ABSTRACT

This paper presents an overview of a project to retrofit and automate 11 check gate structures within a selected section of the eastern canal system in LCRA's Gulf Coast Irrigation Division. LCRA owns and operates three irrigation systems in the lower Colorado River Basin. This project is funded by a combination of funds from the House Bill 1437 Agricultural Water Conservation Program, and a USBR grant. Each check gate structure will consist of two aluminum slide gates with actuators and instrumentation for automatic control, powered by solar panels. Other project features include 3 spill monitoring sites, a radio based data communication system (DCS), and a supervisory control and data acquisition (SCADA) system. Gate manufacturing, and telecom design and installation are being accomplished in-house, with gate design by a contracted engineering firm. The House Bill 1437 (HB 1437) Agriculture Water Conservation Program was developed to meet rising municipal demands in Williamson County (located in the Colorado River Basin of Texas), conserve river water used for irrigation, and maintain agriculture productivity. For more information on this program please visit http://www.hb1437.com. The HB1437 short-term plan established a goal of conserving 10,000 acre feet per year by 2014. This project to automate existing canal check structures is part of this plan. The USBR grant enabled LCRA to include the centralized SCADA component of the project.

The water savings from this project is estimated to be 2,600 acre-feet per year or a 3.5% reduction in the eastern section of Gulf Coast's average annual water diversion (73,000 acre-feet per year). Water management will be improved on the entire eastern section of the system as a result of automating the gates at the head of the system.

INTRODUCTION

The House Bill (HB) 1437 Agriculture Water Conservation Program is an innovative way to conserve agricultural water, meet rising municipal demands, and maintain agricultural productivity. A bill, HB1437, passed by the Texas Legislature in 1999, authorized the Lower Colorado River Authority (LCRA) to transfer up to 25,000 acre-feet of water annually to Williamson County, if the transfer results in "no net loss" of water to the lower Colorado River basin. No Net Loss" is generally defined as the hydrologic condition where the volume of water transferred is equivalent to the volume of water conserved within the LCRA irrigation divisions. The bill also established a conservation surcharge on the transferred water which funds on-farm and in-division agricultural

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conservation projects with the LCRA irrigation division. Additional details of the program history and legislation are available at www.hb1437.com

The LCRA is a conservation and reclamation district created by the Texas Legislature in 1934. LCRA supplies electricity for Central Texas, manages water supplies and floods in the lower Colorado River basin through the operation of six dams, manages three irrigation divisions, develops water and wastewater utilities, provides public parks, and supports community and economic development in 58 Texas counties.

Program Overview

The HB 1437 Agricultural Water Conservation Program began in 2006 with a cost-share grant program to fund precision land leveling on rice farms. This program and verifying the water savings from it will be discussed in another paper presented at this conference. In 2009, LCRA completed a short-term strategy report update to develop 10,000 acft of water supply that recommended two capital improvement projects to be completed by 2014, equipping the Garwood irrigation division to be able to measure water deliveries and bill based on volumetric use, and installing automated gate structures in the irrigation divisions. For more information on this plan please visit http://www.hb1437.com. The latter project evolved into a project to replace and automate gates within the eastern section of the Gulf Coast irrigation division (Figure 2). Following the award of a USBR grant in 2010, the scope of the project was expanded to include a centralized SCADA system, a radio based data communication system, and monitoring of three spill site locations. The estimated amount of water that will be conserved through this project is 2,560 acre-feet per year based on an estimated reduction of 3.5% of average gross diversions for the eastern canal section over the last decade. The purpose of this paper is to describe the system that is being installed and the process LCRA went through to develop this gate rehabilitation project.

This project is a key part of the LCRA's water conservation program for agricultural uses that could be expanded to other divisions and sections in the future. The overall goals of the HB 1437 program are to: 1) Reduce agricultural use of surface water; 2) Plan and implement conservation projects to fulfill obligations of the LCRA contract with the Brazos River Authority (BRA) for HB 1437 water; 3) Provide funds from the Agricultural Water Conservation Fund to implement water conservation projects; and 4) Provide program performance information to the LCRA Board, BRA water customers, and the public in accordance with LCRA Board Policy.

The program is funded through the income stream generated from the conservation surcharge applied to the water sales contract. The conservation surcharge is applied to both reserved water and transferred water. The reservation fee applies to contracted water reserved for future use and is used to help pay the cost of storing and managing reserved water supplies.

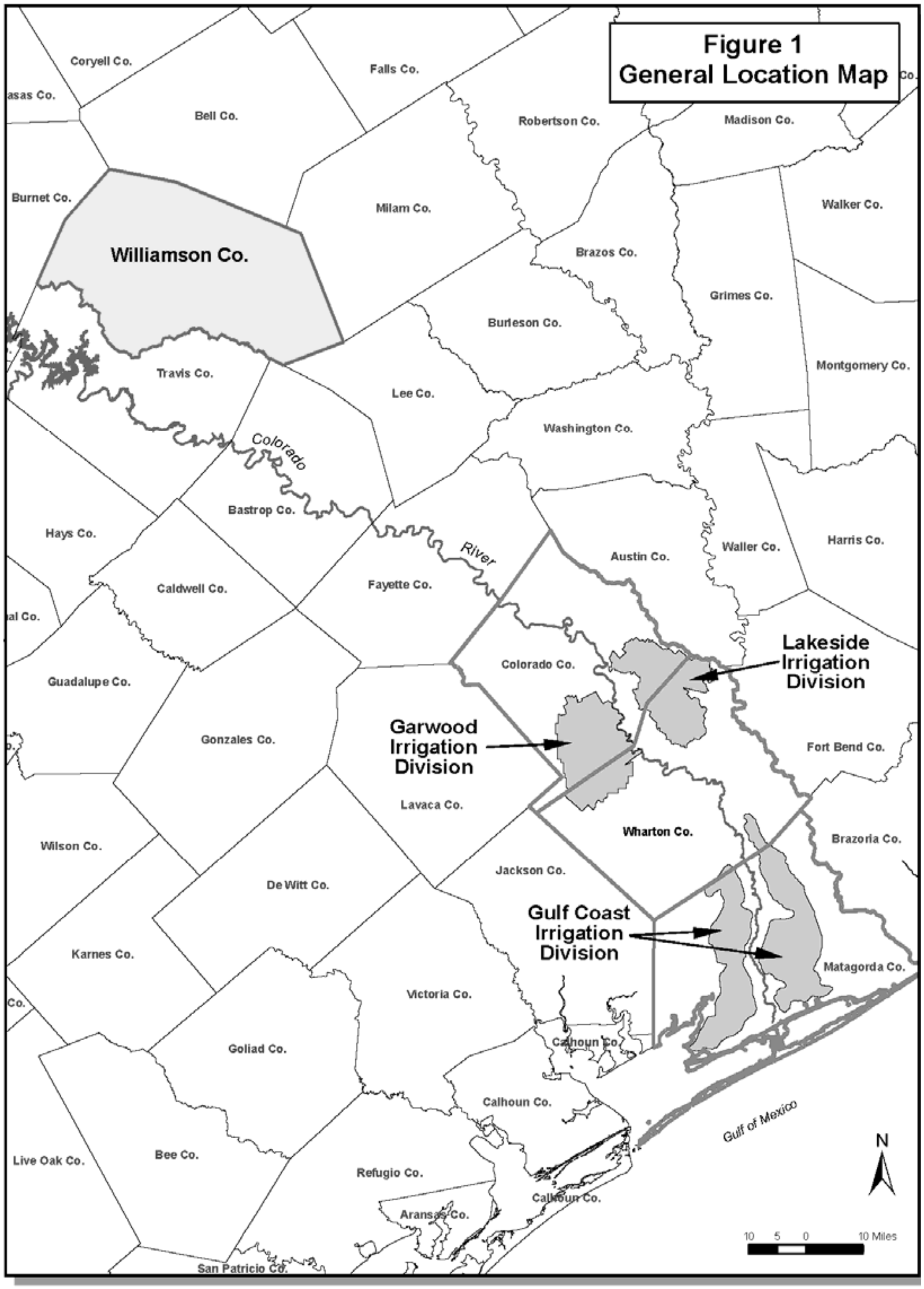

Figure 1
General Location Map

Overview of Gulf Coast Irrigation Division

The Gulf Coast Irrigation Division diverts water from the Colorado River for agricultural use through both a specific water rights permit LCRA holds with the Texas Commission on Environmental Quality for this irrigation operation (acquired in 1960), and the use of stored water from the Highland Lakes, which LCRA operates under more general water rights permits. It has a serviceable area of 490 square miles, 350 miles of managed canals, and approximately 2,400 structures. Figure 2 presents an overview of the entire Gulf Coast Irrigation Division.

The control or "check" structures include bulkheads, water boxes, slide gates, flash board risers, pipes and valves, pipe headers, crossings, siphons, under-drains, bridges and foot bridges. The existing check structures are original and date to approximately the 1920s and 1930s. The picture to the right depicts a typical structure.


Typical Gate Structure

The major crop grown is rice (~85% in most years) with the remainder in turf grass and row crops. In 2010, about 22,300 acres of rice was planted, and 14,400 acres of that was watered for a second crop. In addition, about 7,350 acres was watered for turf, row crops or to create ponds for attracting wildlife. Total diversions for the Gulf Coast Irrigation Division have ranged from approximately 84,000 acre-feet per year to 198,000 acre-feet per year in the last ten years.

LCRA Capabilities

As a large organization with diverse lines of business, LCRA is uniquely positioned to complete most of the work for this gate rehabilitation project internally. The Smithville Rail Fleet Maintenance Facility (LCRA Smithville) maintains more than 2,000 aluminum railcars that transport western coal from Wyoming mines to the Fayette Power Plant. The highly respected metal fabrication team at Smithville supports projects for other LCRA energy and water operations as well, including fabrication of new floodgates for a recent modernization project on LCRA's Max Starke Dam. The slide gates proposed for this project will be fabricated by the Smithville facility.

LCRA also offers low-cost, reliable telecommunications services to employees and a limited number of communities throughout Central Texas. With more than 40 radio sites strategically scattered within LCRA's service territory, radio coverage reaches from counties around the Highland Lakes to Matagorda County along the Gulf Coast. LCRA also has the ability to offer collocation tower space. In the mid 1990's LCRA began investing in maintenance equipment for its three irrigation systems (track hoes, bull dozers etc.) and now is fully capable of all canal maintenance. Today, LCRA has a trained staff capable of installing the check structures proposed in this project with limited training assistance from staff engineers and a consulting engineering firm.

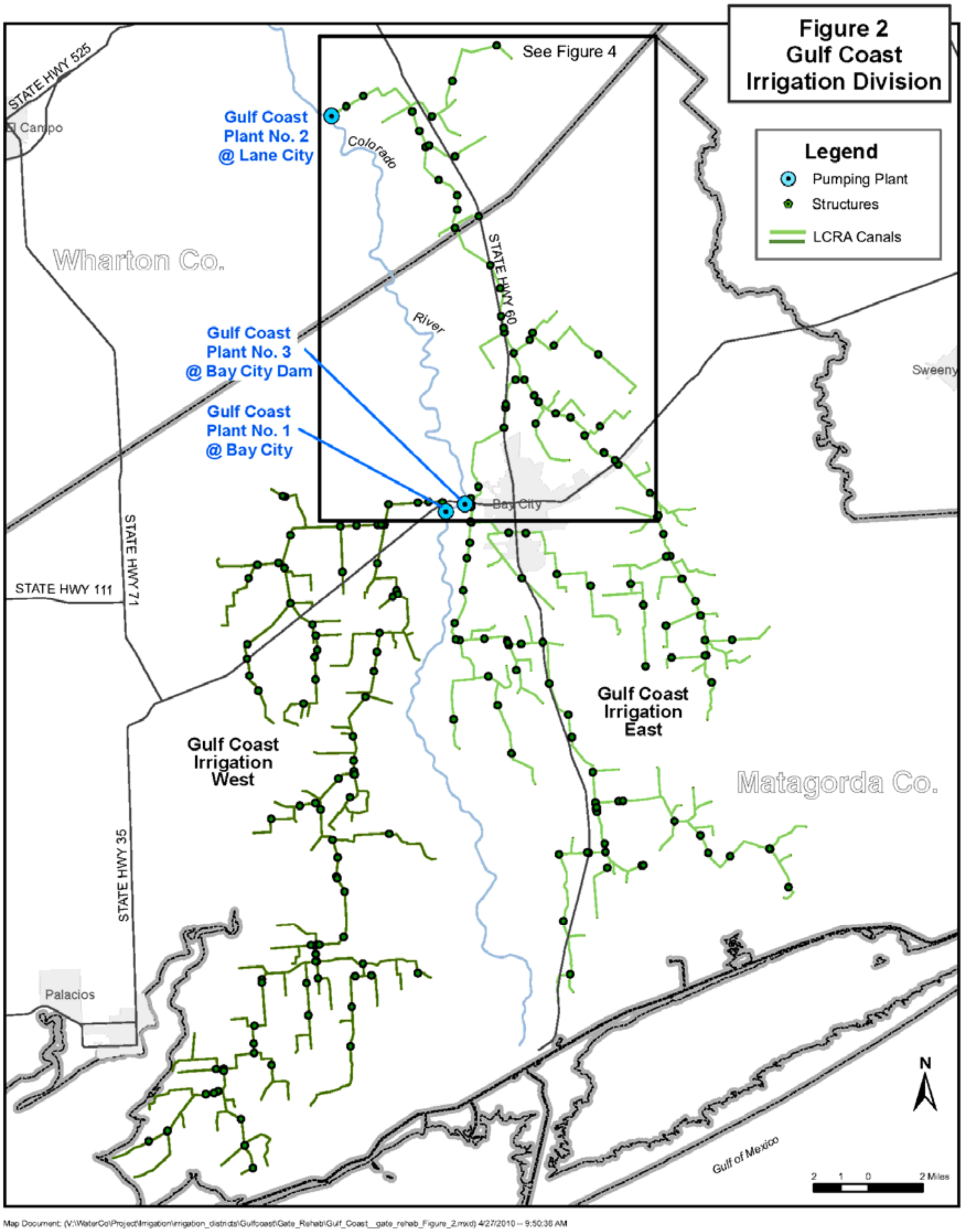

Figure 2. Gulf Coast Irrigation Division

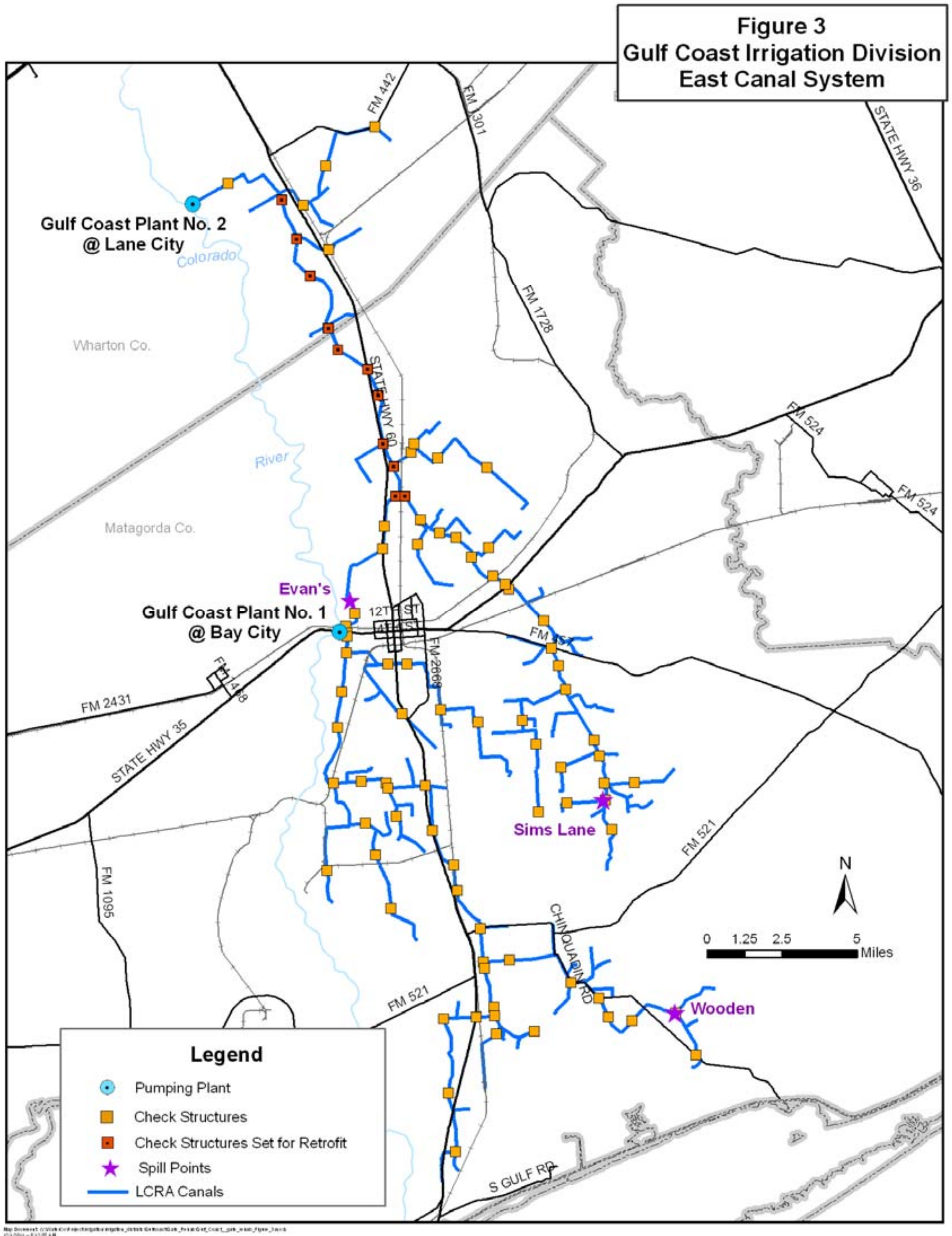

Figure 3. Gulf Coast Irrigation Division, East Canal System

TECHNICAL PROJECT DESCRIPTION

Project Overview and Approach

The objective of this project is to retrofit and automate 11 check gate structures within a selected section of the eastern canal system in LCRA's Gulf Coast Irrigation Division. Each check gate structure will consist of two (2) aluminum slide gates with actuators and instrumentation for automatic control. Other project features include 3 spill monitoring sites, a radio based data communication system (DCS), and a supervisory control and data acquisition (SCADA) system.

Figure 3 presents an overview of the eastern canal system with possible spill monitoring sites. The master radio and SCADA components will be located at the main office, which is adjacent to the Gulf Coast Pumping Plant No.1.

The project is organized into 3 basic areas as shown in Figure 3 and include:

Field Structures and Devices. These components are those elements in the canal system and include the check structures, and spill monitoring sites. The proposed field structures and devices include:

- A total of 22 slide gates, located at 11-check gate structure sites.
- 3 spill or overflow monitoring sites.
- Radio based data communication system necessary for communication and control.
- Solar powered electrical system.
- Remote Terminal Units "RTU" Controllers necessary for controlling the gates actuators.
- SCADA Data Base Application "ClearSCADA" necessary for monitoring and controlling the check gates.

Radio Data Communication System. This work includes the setup and integration of the new structures and devices into the LCRA's radio network. The design, equipment procurement, and installation will be by LCRA Telecom forces to provide a system fully integrated into LCRA's irrigation operations including the planned upgrades to the radio trunk system for LCRA's river diversion pumping stations.

SCADA Control System. This work includes development of the control algorithms, and data acquisition protocols necessary to control and monitor the new gate structures.

The work will be accomplished by a combination of internal LCRA forces and Axiom-Blair Consulting Engineers. Work responsibilities are summarized below:

- Engineering Design Plans – Axiom-Blair
- Gate Fabrication – LCRA Rail Car facility
- Construction – LCRA Irrigation Division Staff
- SCADA and Radio Data Communication System - LCRA Telecommunication (LCRA Telecom) and LCRA Engineering Services.

The SCADA component will add an important feature as it will provide LCRA operations the ability to better control water levels and flow rates within the canal and field delivery systems. This additional control will improve operating efficiency, reduce energy consumption, and conserve water.

Mechanisms by which the expected performance will be achieved include:
Reduce energy consumption by reducing the diving miles required to manually operate check gates.
Reduce pumping hours and motor run time by maintaining full canals and reducing the frequency and number of canal recharges.
Flow estimates by measuring the CFS through the gates using Bernoulli equation.
Conserve water by reducing the number of spills through spill measurement and monitoring.
Conserve water by remotely monitoring water levels.
Conserve water by controlling water levels to utilize the storage capacity of the canal system.

Project Plan and Status

Project execution is organized into the following 10 work tasks.

Task 1 Prepare Design Memorandum

A design memorandum was prepared to document and specify the conditions and design parameters to be used to prepare the construction plans and specifications, operation and control philosophy, and the protocols for integrating the various sub-systems (gate operation, radio telemetry, and instrumentation and control parameters) into a functioning system. Approval to proceed with construction was received from the Texas Historic Commission indicating that the gate structures are not historic monuments requiring special construction consideration, and from USBR, indicating that the project is in compliance with NEPA (National Environmental Policy Act).

Axiom Blair Engineering firm was responsible for the design of the Field Structures and Devices and prepared the design memorandum. It incorporated LCRA's requirements for the radio telemetry system, the SCADA system, and LCRA's Irrigation Division operational requirements.

Task 2 Prepare Plans and Specifications

Plans and specification necessary for the construction of the Field Structures and Devices, i.e. gates, gate operators, and spill monitoring structures have been prepared. A site reconnaissance was completed of each site in January-February 2011 to confirm dimensions for gate fabrication and installation, and any necessary site development work. The irrigation division is in off-season and the canals are empty from Nov-Feb, facilitating this task. This work was led by the design engineer Axiom-Blair, with support and information provided by LCRA.

Task 3 Equip Procurement

This task includes acquiring the necessary equipment and materials for the field devices, radio system, and the SCADA system. All of the major equipment identified for the project was acquired under existing LCRA contracts.

Task 4 Gate Fabrication

This task is to fabricate the 22 USBR type automated slide gates and will be lead by the Lead Engineer at the LCRA Rail Fleet Maintenance Facility in Smithville, TX, which specializes in aluminum fabrication. A test gate was fabricated to work out production details and provide the irrigation division staff a concept of how the gates will be installed.

Gate dimensions and material specifications were modified during the preparation of plans and specifications to a front bolt-on mount design instead of a slip-in design to allow the gate to open above the highest water level in the canal, allowing the manual gate to function as originally designed in the event of a malfunction. The following gate specifications were used:

- Gate Frame: 3-ft to 5-ft wide by 10-ft to 14-ft tall
- Gate Leaf: 3-ft to 5-ft wide by 6-ft tall
- Aluminum Plate: Grade 6061-T651, 0.378” thickness.
- Bolts and Fasteners: all stainless steel. Grade to be determined.
- Slide Strips: UHMW-Black 3M CVT Lam-N-Hard Pressure Sensitive
- Gate Actuator: Venture Actuators MA-8A4358653-64M

Task 5 Gate Installation and Field Construction

This is the construction part of the project and is being completed by LCRA forces. Activities include performing the necessary site preparation for installation of the fabricated gates, upgrading spill monitoring sites and their related support equipment, e.g. actuators, electrical supply, instrumentation etc.

Installation of tower foundations was completed in September 2011. Control cabinets were installed in October-November 2011.

The effort is being led by the LCRA’s Irrigation Division with support and inspection by LCRA Engineering Services. The majority of the work associated with this task must be completed during the non-irrigation season.

Task 6 DCS and SCADA System Integration

This task is related to the development and integration of a radio based data communication system to reliably communicate data from the field sites, (gates and spill sites) to the control room at the Gulf Coast division office. It will be led by the LCRA SCADA engineers with support from the LCRA Telecom group.

The radio systems being installed are GE iNet900 II radios for the 11 check structure and 3 spill monitoring sites. These radios will communicate back over LCRA's SONET Microwave network to Bay City Control Room ClearSCADA Server.

LCRA Telecommunications group has conducted a detailed signal survey to confirm that no repeaters are needed. All of the sites are within 20 miles of the Master radios.

General specifications of the radio system are:

- Location of Tower: Existing LCRA tower at the Bay City office and Lane City
- FCC and RF Band: Unlicensed 902-928 MHZ ISM
- Number data radios:
    - Check Structures – 11
    - Spill Structures – 3
- Antennas (for both types) – MAXRAD 12db Onm i and Yagi
- Minimum Antenna height: 30-ft
- Radio types
    - Check structure: GE iNet900 II
    - Spill Structures: GE iNet900 II
- Power Supply and Battery Backup: 12 VDC 3A minimum – 300AH battery capacity
- Surge and Lightening Protection: To be determ ined- as required by LCRA Telecom

Data from each site will be polled and received at two master radios located at the Bay City Office and the Lane City. Radio data will be fed into a the Irrigation SCADA network. The antennas are located on existing LCRA towers.

The radio towers ended up being re-designed from the design envisioned in the original grant proposal (based on a similar project in the Rio Grande Valley) to follow LCRA safety standards and allows maintenance to be done by climbing the tower instead of needing a bucket truck to perform maintenance. The original proposal from LCRA Telecom was for a much more expensive and larger tower with a larger concrete base. The final design was a compromise to take safety concerns as well as cost concerns into account.

Task 7 SCADA Programming

This task includes programming of two components: the first is the SCADAPack RTU controller programmed using Telepace software and data reporting necessary to operate and monitor the gate installations via the radio data communication system. All Communication will be done over TCP/DNP3 Protocal. This work will be led by Axiom Blair with support from LCRA. LCRA will provide to Axiom Blair control equipment and SCADA software including:

- SCADAPack 350 RTU's.
- Telepace Programming Software.

The second SCADA component is ClearSCADA advanced human machine interface (HMI). This work will integrate the new gate system into LCRA's radio data communication systems for the pumping plants and other internal systems required by LCRA. The canal gates will have the ability to be controlled remotely from the Bay City Office control room. An LCRA Irrigation Operator will be able to set the gates in auto upstream level control or (STO) "Set to Order" gate height. This advanced HMI programming work will be done by LCRA Engineering Services and will include:

- ClearSCADA Data Bace Software ViewX Run Time, Alarming, and Historian.
- The server will be a Dell R410 Class Server

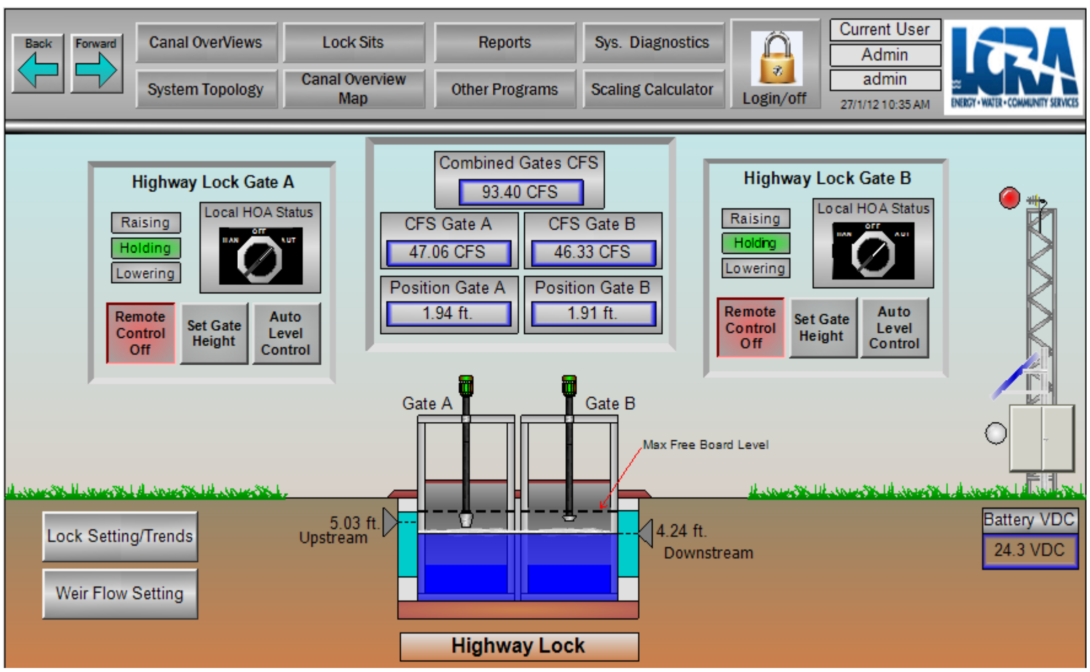

Figure 4. SCADA control user interface

Task 8 Startup and Acceptance Testing

This task includes the work required to integrate all of the various sub-systems; check structures, spill monitoring, and radio DCS into a functional check structure monitoring and control system. Work will include performance and reliability testing, and acceptance testing required by Gulf Coast Irrigation Division operations. This effort will be led by LCRA Engineering Services.

Task 9 Regulatory and Conservation Reporting

This task includes the work required to comply with federal laws and regulations related to the project, and the project performance reports required by USBR. These efforts have been led by LCRA with assistance from USBR and LCRA's cultural resources team, which assisted with the assessment of state historical commission rules. Approval to proceed with construction was received from the Texas Historic Commission in the fall of 2010 and the USBR officially notified LCRA that the project meets all regulatory requirements in the fall of 2010. A final project report to USBR is due at the end of the project.

Task 10 Project Management

This task includes the work necessary to plan, execute, procure, control, and closeout the proposed project. These project management functions include but not limited to organizing and directing the project team, progress meetings with USBR, processing payment requests, updating project schedule, and preparation of progress reports.

CONCLUSION

To date, the successful collaboration of many LCRA departments has led to the development of quality gates and communication systems for the Gulf Coast Irrigation Division's gate rehabilitation and control project. The main challenge with this project has been managing cost over-runs. There was a philosophical difference of opinion between LCRA Telecom services and LCRA's irrigation division staff in the design requirements for the radio towers. Most of the work done by LCRA Telecom services is for much larger projects where 100% reliability is essential and the cost of a radio tower is a small percentage of the budget, such as Substation Yards and vital emergency radio systems for Fire, EMS and Police. Irrigation division operating and maintenance budget is picking up a substantial portion of the labor cost shortfall, and the LCRA Board recently authorized an additional $90,000 to be spent from the HB1437 fund to complete the project. The short project completion window of 24 months required by USBR has also been a challenge since re-design decisions had to be made quickly to adhere to the tight schedule. If all or a substantial proportion of LCRA's three irrigation divisions are to be retrofitted with these gates, the cost per site must decrease to become economically feasible on a large scale. If the same gate design is retained, design engineering costs will reduce substantially with future projects. Another remaining challenge with this project is to quantify the water savings achieved as a result of these gate improvements to verify the current water savings estimate. The main purpose of installing instrumentation at three spill points was to assist with this goal. Water delivery efficiency will also be assessed, taking weather fluctuations into account, but it could take five years or more to accumulate the data needed to verify savings estimates.

A COMPARISON OF LABORATORY AND FIELD CALIBRATION OF THE ECH2O EC-20 SOIL MOISTURE PROBE FOR SOILS IN THE MIDDLE RIO GRANDE VALLEY

Kristoph-Dietrich Kinzli[1*]
Nkosinathi Manana[2]
Ramchand Oad[3]

ABSTRACT

Throughout the American West irrigated agriculture has been targeted to increase water use efficiency. Soil moisture sensors offer a method to achieve efficiency improvements but have found limited use due primarily to high cost and lack of soil specific calibration equations. In this paper we examine the ECH2O EC-20 soil moisture sensor, a low cost capacitance sensor and develop a unique laboratory calibration method. Field and laboratory calibration equations were developed for 6 soil types in the Middle Rio Grande Valley. The average absolute error in volumetric water content for field calibration was 0.43 m^3/m^3, and 0.012 m^3/m^3 for the laboratory calibration. The factory calibration equation for the EC-20 was also evaluated and found to yield an average absolute error of 0.049 m^3/m^3. We found that the EC-20 is a reliable, cost effective, and accurate sensor, and recommend that the laboratory calibration method presented here be used to obtain maximum accuracy. We also recommend that the field calibration of the EC-20 soil moisture sensor be foregone, as this type of calibration exhibits large error rates. Additionally, it was found that the field calibration method was time consuming, covered a small range of moisture content values and was destructive to the area around installed sensors, which could lead to measurement errors.

INTRODUCTION

The Middle Rio Grande Valley in central New Mexico is a prime example of a region where agricultural water users have been targeted to increase water use efficiencies due to increasing demands, interstate compacts and instream flow requirements linked to federally listed endangered species. To improve water delivery efficiencies, the New Mexico Interstate Stream Commission and the Middle Rio Grande Conservancy District have developed a Decision Support System over the last several years. The Decision Support System monitors soil moisture levels and soil water depletion, and schedules irrigation according to crop demand which increases water delivery efficiencies (Oad et al. 2009; Gensler et al. 2009). In order to validate the moisture depletion calculated using

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∞ Nathi Manana passed away at his home in South Africa March 17, 2011. You will be missed "ungami wami."
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the Decision Support System, it was necessary to deploy soil moisture sensors in several fields to determine actual depletions. To ensure that the data collected was as accurate as possible, both laboratory and field calibration equations for moisture sensors were developed throughout the Middle Rio Grande Valley.

An available probe that has found implementation is the ECH20 EC-20 (Decagon Devices, Pullman, WA, 2006b) dielectric probe from Decagon Devices, see Figure 1. The ECH2O EC-20, which offers a low cost alternative to other capacitance type meters (Kizito et al. 2008; Saito et al. 2008; Sakaki et al. 2008; Bandaranayake et al. 2007; Nemali et al. 2007; Plauborg et al. 2005), has been used to improve irrigation management for citrus plantations (Borhan et al. 2004) and the precision of the ECH20 EC-20 is such that it can be used for greenhouse operations and to schedule field irrigations (Nemali et al. 2007). The main benefit of the ECH2O sensor is that it is one of the most inexpensive probes available and therefore can be widely used and implemented (Christensen, 2005; Luedeling et al. 2005; Riley et al. 2006). EC-20 sensors allow for the measurement of water content associated with saturation, field capacity, and wilting point, along with the redistribution pattern of soil water and possible drainage below the root zone. This information can be used to decide the time and amount of irrigation (Bandaranayake et al. 2007).

Through previous research it has been found that dielectric sensors often require site specific calibration either through field methods or laboratory analyses. Inoue et al. (2008) and Topp et al. (2000) found that it was necessary to perform site specific calibrations for capacitance sensors to account for salinity concerns and Nemali et al. (2007) found that it was necessary to calibrate the ECH2O sensors because output was significantly affected by the electrical conductivity of the soil solution. Other studies have found that site specific corrections are required for mineral, organic, and volcanic soils (Paige and Keefer 2008; Bartoli et al. 2007; Regelado et al. 2007; Malicki et al. 1996). Despite the need for site specific calibration limited published data for ECH20 sensors are available and further studies on the EC-20 are needed (Saito et al. 2008; Sakaki et al. 2008; Bandaranayake et al. 2007; Norikane et al. 2005; Bosch, 2004).

Laboratory calibration of the EC-20 can be completed by performing a series of measurements on multiple soil samples with varying moisture content and developing regression equations from the collected data. This method has proven successful for the calibration of several dielectric instruments (Seyfried and Murdock 2004; Veldkamp and O'Brien 2000). Field calibration can be accomplished through regression with numerous gravimetric samples and is an approach that has been used in the calibration of capacitance probes and TDR sensors (Geesing et al. 2004; Walker et al. 2004; Kelleners et al., 2004; Morgan et al. 1999).

The objectives of this study were to:

- Perform a field calibration of the ECH20 EC-20 soil moisture sensor for various soil types in the Middle Rio Grande Valley

- Perform laboratory calibrations using a modified method for the ECH20 EC-20 soil moisture sensor for various soil types in the Middle Rio Grande Valley
- Compare the laboratory and field calibrations and evaluate the laboratory method and;
- To determine the difference displayed by both methods in regards to the manufacturer's generic calibration equation

The goal of this research was to provide irrigators and researchers with a precise laboratory calibration method, specific laboratory and field calibration equations, and an understanding of the accuracy that can be expected using various calibration methods for the ECH2O EC-20 soil moisture sensor. Although the focus of this research is related to irrigated agriculture, other users of soil moisture sensors in various applications could benefit from this research.

MATERIAL AND METHODS

Eight fields, irrigated using border and flood irrigation, within the Middle Rio Grande Valley were chosen for soil moisture monitoring using ECH2O EC-20 sensors. The EC-20 probe has a flat design for simple insertion and allows for continued monitoring at a user defined interval. The overall length of the sensor is 20.5 cm with a width of 3.1 cm, a blade thickness of 0.1 cm and a 6 cm sensor head length (Figure 1). The total sampling volume of the probe is between 128 and 256 cm^3 depending on soil water content (Bandaranayake et al. 2007). The ECH2O EC-20 soil probe measures the capacitance of the surrounding soil medium, which is related to dielectric permittivity of the medium (Kizito et al. 2008). The final output from the sensor is either in a voltage or a raw count value that can be converted to a volumetric water content using calibration equations (Kelleners et al. 2005).

Figure 1. ECH2O EC-20 Soil Moisture Sensor

Details on the EC-20 sensor measurement principle and function are reported by the manufacturer (Decagon Devices, 2006a).

The standard Decagon calibration equation using millivolts for the EC-20 is given as:

$$\theta(m^3/m^3) = 0.000695(mV) + (-0.29) \quad (1)$$

For the Em5B Decagon logger output of rawcounts the equation is:

$$\theta(m^3/m^3) = 0.000424(\text{rawcount}) + (-0.29) \quad (2)$$

In some instances, such as the use of a datalogger other than the Decagon loggers it may be necessary to convert between millivolts and raw counts. If millivolt output is desired, the rawcounts can be converted for the Em5b datalogger using the following equation:

$$mV= [\text{rawcounts } (3000 \text{ (logger excitation voltage)})]/4096 \quad (3)$$

Two ECH20 EC-20 soil moisture probes were installed in each field at a depth of 20 cm and 61 cm. The Natural Resource Conservation Service (NRCS) recommends installing soil moisture sensors at 15-20 cm and 46-61 cm to obtain profiles in the Middle Rio Grande Valley. The sensors were installed 15 m into the field away from the border to minimize edge effects by digging a shallow trench into the field at a distance of one half the field lengths from the irrigated end. This ensured that the sensors would be obtaining a representative measurement while not impeding field trafficability. Once the sensors were installed the trench was refilled with soil and packed to prevent preferential flow during irrigation events.

This resulted in a total deployment of 16 ECH20 EC-20 sensors. During installation a four liter soil sample was obtained from each depth in order to determine soil type, electrical conductivity, and perform laboratory sensor calibrations. All probes were installed vertically using the factory recommended tools consisting of an auger, blade for making a pilot hole, and the ECH2O insertion tool. The insertion tool is critical for the installation of the EC-20 sensors as it prevents the sensor from being snapped while it is being inserted. The installed sensors were connected to an Em5b datalogger, mounted on a T-post at the edge of the field, which reads electrical rawcounts of the EC-20 sensor. The Em5B was set to record soil moisture every 60 minutes. Figure 2 displays the location of the fields instrumented with EC-20 sensors. Fields 1, 2, 3, and 6 were planted in alfalfa and fields 4, 5, 7, and 8 were planted in grass hay. At the beginning of the irrigation season in early March all fields were fertilized at rates between 110 and 168 kg/hectare.

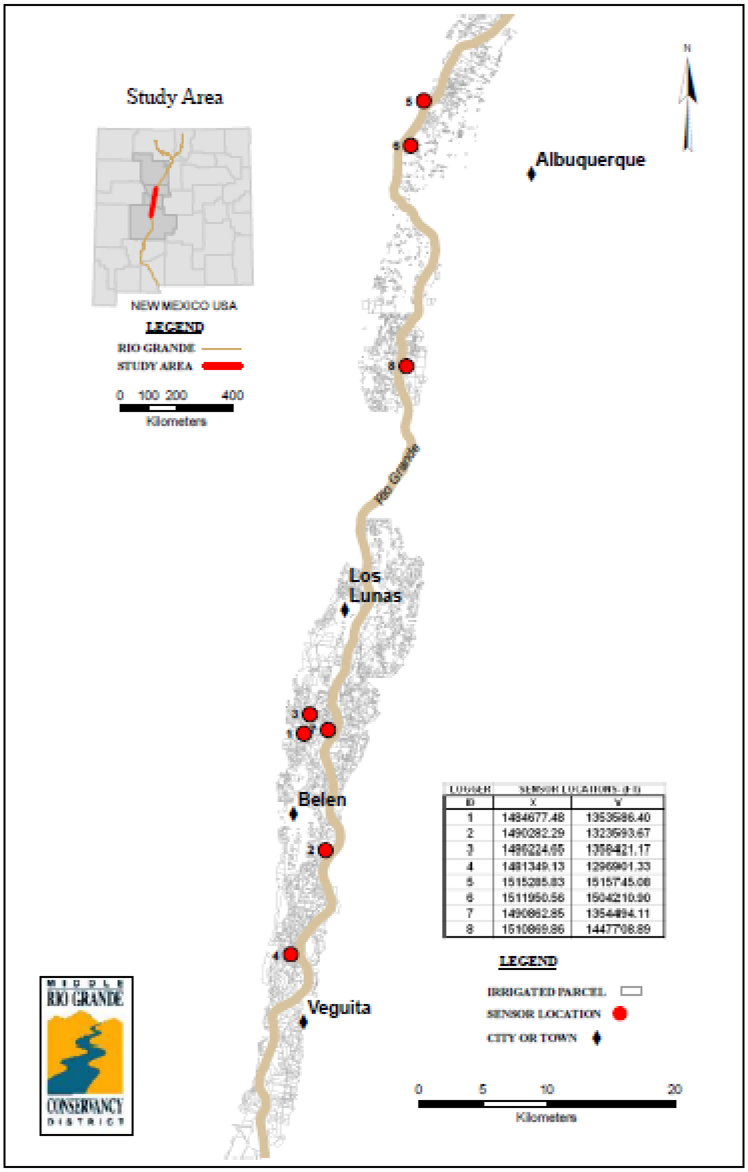

Figure 2. Soil Moisture Sensor Locations in the Middle Rio Grande Valley

In order to determine soil type for all 16 installation locations both sieve and hydrometer analyses were completed. In addition to this analysis electrical conductivity was determined for each soil using the 1:1(V:V) soil: water extract method and a HATCH HQ 40d electrical conductivity sensor.

Analysis on soil temperature was not conducted as previous research has shown that temperature effects on ECH20 sensors are minimal (Kizito et al. 2008; Norikane et al. 2005; Campbell, 2002). Specifically, (Bandaranayake et al. 2007) showed that temperature changes of 30 degrees Celsius resulted in a 0.047 m^3/m^3 change in water content for the EC-20 soil moisture sensor. Other researchers have also found that changes in EC-20 measured water content are minimal with 0.0022m^3/m^3 changes per degree C (Nemali et al. 2007).

To address concerns related to soil salinity influencing field measurements, analysis was conducted on collected data to determine if large spikes in sensor output existed. Bandaranayake et al (2007), found that salinity due to fertilization increased sensor output by 200mV which corresponds to .14 m^3/m^3 and that salinity effects could be determined graphically. Using the hourly data collected by the sensors in the field it was possible to determine if spikes in sensor output existed that did not correspond to an irrigation event.

Field Calibration

Throughout the irrigation season, gravimetric samples were taken for each of the 16 deployed sensors at the exact depth of the sensor installation (either 20 or 61 cm) and in close proximity (less than 60 cm) to the sensor. It was not feasible to collect samples closer to the sensor due to possible damage to the sensor and sensor cables. Therefore, field samples were not directly co-located with the sensor but this was deemed appropriate due to limited spatial soil variability in the monitored fields. Similar sampling techniques used by other researchers have been effective at developing field calibration equations (Bandaranayake et al. 2007; Kaleita et al. 2005). The collection of the samples was timed to account for pre and post irrigation soil moisture levels. Overall, five measurements with two replicates per measurement were collected for each sensor installation. These two replicates were averaged to determine volumetric water content and field bulk density. The samples were collected using an Oakfield Soil Sampling Auger and stored in airtight soil moisture tins. These samples were weighed and oven dried at 105^0C for 24 hrs and reweighed to determine volumetric water content and the field bulk density of each sample. This volumetric water content from the two samples was correlated to a rawcount reading from the Em5b datalogger for the hour during which the sample was taken.

Laboratory Calibration

Laboratory calibrations were performed using a modified approach to the manufacturer's suggested calibration method (Decagon, 2006b). For the laboratory calibration of ECH2O EC-20 sensors a 15 cm diameter piece of PVC pipe was used as a calibration cylinder (volume 2100 cm^3). Before calibration began the soil samples were oven dried for a period of 24 hrs at 105^o C. Subsequently the cylinder was packed to the exact bulk density measured in the field, which was accomplished by packing the soil into the cylinder by sections. Once the oven dry soil was packed into the cylinder at field bulk density, the EC-20 sensor was inserted using the manufacturer recommended insertion tool. The probe was allowed to equilibrate, which involved taking readings every 30 seconds until the readings did not change. Then the final equilibrated reading of the raw counts was recorded using an Em5b datalogger, and the probe was removed from the calibration cylinder

After removing the probe from the cylinder, it was necessary to obtain a volumetric sample to determine soil moisture content for a given sensor output. This was accomplished by using two small cylinders constructed out of copper water pipe with volumes of 23.40 and 23.73 cm^3 respectively. To decrease the effect of compacting the soil in the measurement cylinder, the edges of the copper cylinders were beveled to a thin, sharp edge using a metal file. The cylinder and the volume of soil contained in it were then extracted from the test cylinder. The samples were trimmed from the top and bottom edges of the cylinder to ensure accuracy in the volume measurements and emptied into soil moisture sampling tins and weighted. The samples were then placed in an oven at 105^0 C for 24 hours and re-weighted thereafter. Volumetric water content was then calculated for each of the soil samples. Bulk density was also determined and used to verify that the field bulk density was indeed replicated in the calibration cylinder.

This procedure was completed for each of the 16 soil types by subsequently adding 100 ml of water to the soil to increase the moisture content and develop calibration curves. Once readings were obtained from the oven dry sample, the soil inside the calibration cylinder was placed in a pan where 100 ml of water were added. The sample was then mixed for a period of 10 minutes to ensure uniform distribution of the water throughout the soil. Once mixing was complete the soil was packed back into the calibration cylinder at the field bulk density. The EC-20 probe was inserted again, the equilibrated raw count recorded, and two volumetric samples were removed to determine the water content. This process was repeated until the water content of the soil reached saturation which was determined through laboratory analysis. In most cases this resulted in at least 7 measurements consisting of a raw count and a soil moisture content. A more detailed explanation of calibrating capacitance probes can be found in Starr and Palineanu (2002) and Polyakov et al. (2005).

From the collected field and laboratory data it was possible to develop predictive regression equations relating raw count to volumetric water content. Based on the work of several researchers (Bandaranayake et al. 2007; Mitsuishi and Mizoguchi, 2007; Kaleita et al. 2005; Plauborg et al. 2005; Fares et al. 2004; Paltineanu and Starr, 1997; Gaudo et al. 1993) and advice from Decagon Devices (Gaylon Campbell – personnel communication) linear and polynomial regression equations are most appropriate for capacitance type sensor calibration. Both linear and polynomial equations were developed for each soil type and the best fit for each soil type was utilized in subsequent analysis. The best fit regression equation for each soil type was selected based on the highest coefficient of determination.

In order to determine the accuracy of the factory, and developed field, and laboratory calibration equations, the absolute error in water content between the predicted volumetric water content and the actual measured water content was calculated using the following equation:

$$\text{ABS Error} = (\text{Sum ABS } [\theta_{\text{Equation}} - \theta_{\text{Actual}}]\ )/\ N \qquad (4)$$

Where N is the number of observations.

The absolute error in water content was selected as being appropriate based on the preliminary findings that several of the field calibration equations exhibited both over and under prediction for the same soil type.

RESULTS

From the soil analysis it was determined that the 16 installation sites were characterized by six soil textures consisting of sand, sandy loam, silt loam, loam, clay loam, and clay. The field bulk densities varied from 1.4 to 1.6 g/cm^3. The EC analysis revealed variations from 2.0 dS/m to 6.29 dS/m. No sample exceeded 8 dS/m where capacitance sensors experience distortion. Table 1 displays the results of the soil analyses.

Table 1. Soil Characteristics for Monitored Fields in the Middle Rio Grande Valley

Soil Class	Field	Depth (cm)	% Sand (> .05mm)	% Silt (.002 to .05mm)	% Clay (< .002mm)	Field Bulk Density (g/cm^3)	pH 1:1	EC (ds/m) 1:1
Sand	3	61	90.0	5.0	5.0	1.59	7.80	4.29
Sand	5	61	96.0	2.0	2.0	1.52	7.93	3.14
Sand	8	61	96.0	2.0	2.0	1.60	7.58	2.89
Sandy Loam	3	20	76.0	14.0	10.0	1.54	7.79	3.07
Sandy Loam	4	61	78.0	16.0	6.0	1.68	8.07	2.00
Sandy Loam	7	61	60.0	29.0	11.0	1.51	7.75	2.90
Sandy Loam	8	20	67.0	19.0	14.0	1.48	6.95	1.73
Silt Loam	1	61	23.0	52.0	25.0	1.62	7.71	2.71
Loam	2	61	44.0	48.5	7.5	1.56	7.85	4.39
Loam	4	20	43.0	31.0	26.0	1.47	7.62	3.80
Loam	5	20	36.0	48.0	16.0	1.37	7.41	6.29
Loam	7	20	43.0	35.0	22.0	1.54	7.72	3.20
Clay Loam	1	20	40.0	27.5	32.5	1.42	8.03	3.51
Clay Loam	6	20	23.0	50.0	27.0	1.47	7.75	4.00
Clay Loam	6	61	23.0	47.0	30.0	1.52	7.87	3.60
Clay	2	20	20.0	27.5	52.5	1.41	7.85	5.23

Analysis of collected data did not show the significant spikes in output associated with salinity described by Bandaranayake et al. 2007 which exhibited changes of 0.14 m^3/m^3. Figure 3 displays the soil moisture depletion measured throughout the 2008 irrigation season for the 20 cm sensor installation on field 5 which is a loam soil and the 20cm sensor installation on field 6 which is a clay loam soil. The other 14 installations exhibited similar depletion and irrigation patterns without spikes associated with salinity with soil moisture depletion ranging from 0.05 m^3/m^{3}for clay and clay loam soils to 0.15 m^3/m^3 for loam and sandy loam soils. A major reason that salinity did not affect the sensor installations is that the irrigation practices in the Middle Rio Grande Valley are flood irrigation with the average applications being 15 cm per irrigation event for the monitored fields (Kinzli, 2010). This amounts to 138 cm per year on average for the monitored fields (Kinzli, 2010). The large amounts of water applied insured adequate flushing of salts and kept the salinity values low during the irrigation season (Kinzli, 2010). Additionally, the farmers on the monitored fields did not fertilize during the irrigation season.

Field Calibration

The data from the field calibration showed that a significant amount of scatter existed with regard to the factory calibration equation. The data points from the field calibration were clustered together and covered a minimal range of volumetric water contents compared to the laboratory calibration. This is the case because the finer soils exhibited a minimal variation in volumetric water content throughout the irrigation season with maximum changes being around 0.05 m^3/m^3 (Figure 3). The curvature of the collected points can be explained using linear equations (Figures 4 and 5). The slope of data points collected from the fields was in most cases significantly different from the factory equation slope.

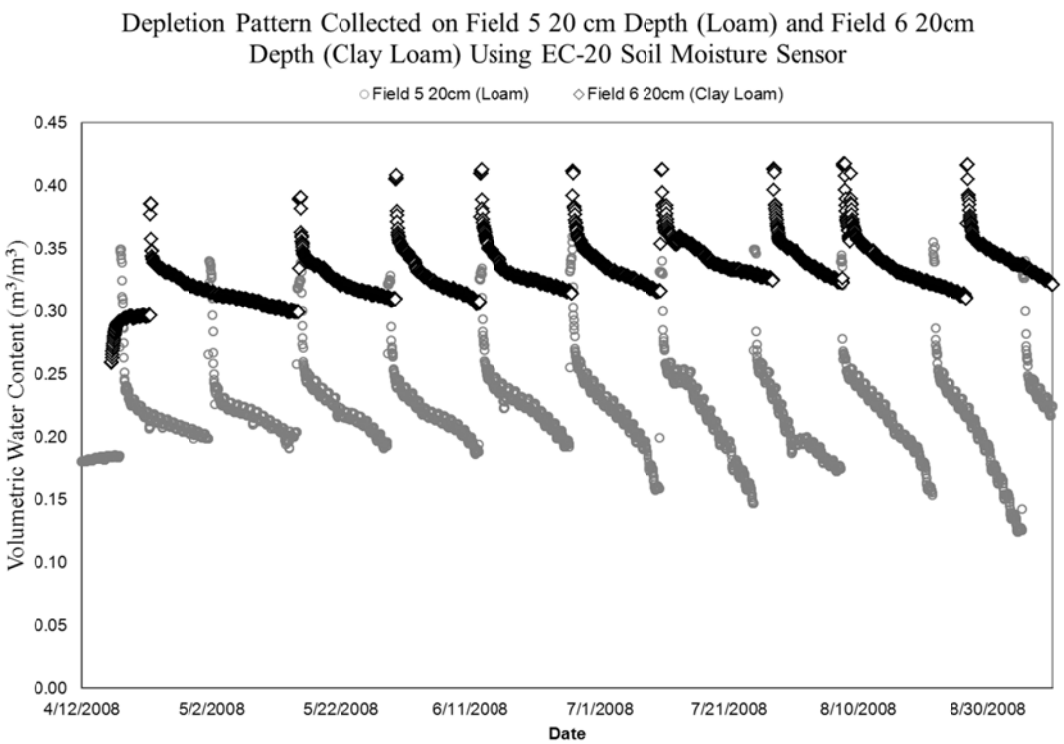

Figure 3. Depletion Pattern Collected on Field 5 20 cm Depth (Loam) and Field 6 20cm Depth (Clay Loam) Using EC-20 Soil Moisture Sensor

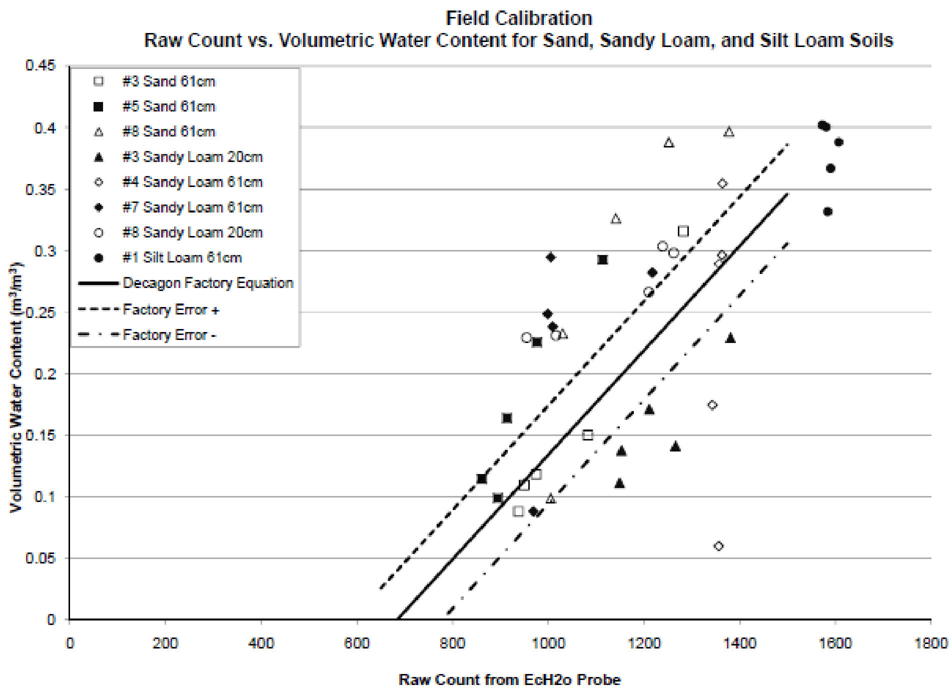

Figure 4. Field Calibration Compared to Factory Calibration Curve for Sand, Sandy Loam, and Silt Loam Soils

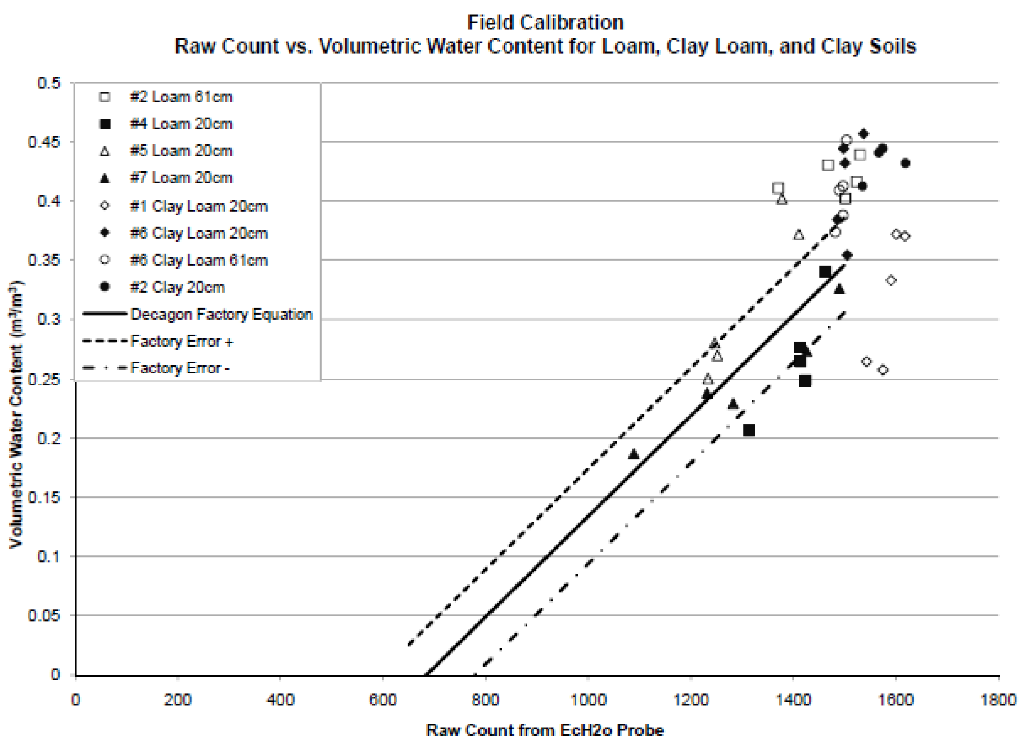

Figure 5. Field Calibration Compared to Factory Calibration Curve for Loam, Clay Loam, and Clay Soils

The field calibrations were most successful for sand soils (Figure 4) where a larger range of moisture contents was obtained from the field measurements. In the other five soil textures the data collected from the field sampling was bunched together in tight clusters at higher volumetric water content values. This is the case because during the irrigation season the variation in soil moisture is reduced as percent of fine material in the soil increases. For sandy loam the field calibration showed extreme variation and for loam, silt loam, clay loam, and clay (Figure 5), the field calibration resulted in a cluster of points located at the upper end of the volumetric content range.

The development of calibration equations from the field data resulted in linear equations for all 16 sensors. The results for the field calibration are displayed in Table 2. The absolute error ranged from 0.036 m^3/m^3 to 3.18 m^3/m^3 with an average absolute error of 0.43 m^3/m^3 for the 16 developed equations. The adjusted coefficient of determination varied between -0.26 and 0.95 with an average value of 0.56. The equations developed for sand collectively showed the lowest average absolute error of 0.076 m^3/m^3 with an average adjusted coefficient of determination of 0.85. The average absolute errors and adjusted coefficients of determination by soil texture for sandy loam, loam, and clay loam were 0.939 m^3/m^3 (0.54), 0.128 m^3/m^3 (0.57) and 0.514 m^3/m^3 (0.40) respectively. For silty loam and clay only one sample was collected and the absolute error and adjusted coefficient of determination for these was 0.702 m^3/m^3 (0.76) and 0.160 m^3/m^3 (-0.04) respectively. The equations that exhibited the largest absolute error were Field 4 61 cm with 3.18 m^3/m^3, Field 1 61 cm with 0.702 m^3/m^3, Field 1 20 cm with 0.687 m^3/m^3, and Field 6 61 cm with 0.686 m^3/m^3.

Table 2. Results of Field Calibration for EC-20 Soil Moisture Sensor

Soil Class	Field	Depth (cm)	Regression Equation (x =raw count)	Adjusted R^2	Range in volumetric Water Content	Abs Error (m^3/m^3)
Sand	3	61	7.68E-04x - 5.52E^{-01}	0.880	0.09-0.29	0.06
Sand	5	61	6.26E-04x - 4.98E^{-01}	0.950	0.08-0.32	0.06
Sand	8	61	7.06E-04x - 5.32E^{-01}	0.710	0.10 -0.40	0.11
Sandy Loam	3	20	4.14E-04x - 3.52E^{-01}	0.690	0.11-0.23	0.06
Sandy Loam	4	61	7.46E-03x - 9.84E^{+00}	0.880	0.06-0.35	3.19
Sandy Loam	7	61	1.01E-04x + 1.59E^{-01}	-0.260	0.09-0.29	0.26
Sandy Loam	8	20	2.37E-04x - 3.73E^{-03}	0.850	0.23 -0.30	0.26
Silt Loam	1	61	2.19E-03x - 3.13E^{+00}	0.760	0.33-0.40	0.70
Loam	2	61	7.44E-05x + 3.10E^{-01}	-0.180	0.40-0.44	0.13
Loam	4	20	7.81E-04x - 8.30E^{-01}	0.710	0.21-0.34	0.22
Loam	5	20	7.70E-04x - 6.90E^{-01}	0.870	0.25-0.40	0.13
Loam	7	20	3.15E-04x - 1.60E^{-01}	0.890	0.19-0.33	0.04
Clay Loam	1	20	1.71E-03x - 2.38E^{+00}	0.680	0.26-0.37	0.69
Clay Loam	6	20	1.13E-03x - 1.29E^{+00}	0.000	0.35-0.46	0.17
Clay Loam	6	61	2.85E-03x - 3.86E^{+00}	0.530	0.37-0.45	0.69
Clay	2	20	1.93E-04x + 1.28E^{-01}	-0.040	0.41-0.44	0.16

Laboratory Calibration

The data from the laboratory calibration showed much less scatter than the developed field calibration equations. The data from the lab calibration exhibited exclusively linear and polynomial relationships which covered a large range of volumetric water contents (Figures 6 and 7). The slope of data points collected during the laboratory calibration was similar to the factory equation.

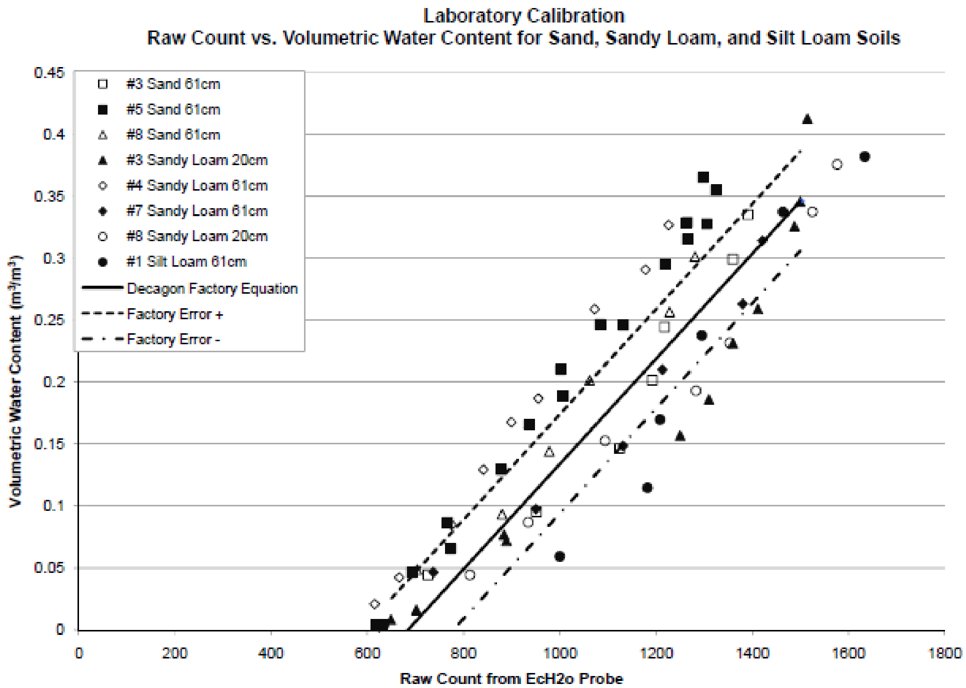

Figure 6. Laboratory Calibration Compared to Factory Calibration Curve for Sand, Sandy Loam, and Silt Loam Soils

The laboratory calibrations were successful for all 16 soils. The laboratory calibration allowed for precise management of bulk density and water content and therefore a large range of moisture contents was obtained for developing equations. For all 16 soil types, the variation in obtained data was minimal which resulted in accurate calibration equations.

The development of calibration equations from the laboratory data resulted in mostly polynomial equations. The results from the laboratory calibration effort are displayed in Table 3. The absolute error ranged from 0.00053 to 0.031 m^3/m^3 with an average absolute error of 0.012 m^3/m^3 for the 16 developed equations. The adjusted coefficient of determination varied between 0.880 and 0.998 with an average value of 0.979. The equations developed for loam collectively showed the lowest average absolute error of 0.0072 m^3/m^3 with an average adjusted coefficient of determination of 0.995. The average absolute errors and coefficients of determination by soil texture for sand, sandy loam, and clay loam were 0.014 m^3/m^3 (0.973), 0.012 m^3/m^3 (0.981) and 0.012 m^3/m^3 (0.988) respectively. For silt loam and clay only one sample of the soil texture was collected and the absolute error and coefficient of determination for these was 0.031 m^3/m^3 (0.880) and 0.011 m^3/m^3 (0.992) respectively. The equations that exhibited the largest absolute error were Field 1 61 cm with 0.031 m^3/m^3, Field 3 20 cm with 0.019 m^3/m^3, Field 5 61 cm with 0.017 m^3/m^3, and Field 8 61 cm with 0.017 m^3/m^3.

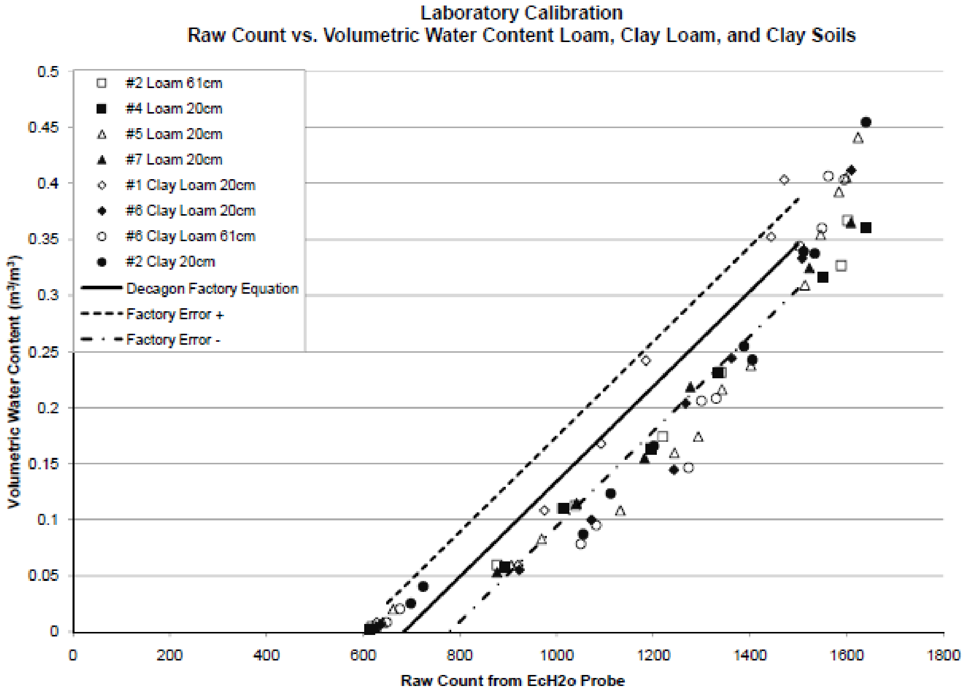

Figure 7. Laboratory Calibration Compared to Factory Calibration Curve for Loam, Clay Loam, and Clay Soils

Overall, it was found that in cases where a polynomial equation exhibited a higher coefficient of determination the use of the polynomial over a linear equation was warranted. The absolute error rates were significantly higher for linear equations when compared to polynomial equations and overall the absolute error rate was .029 m^3/m^3 less for the polynomial equations. This was tested using an F-Test-two sample for variance analysis at an α level of 0.05 for the 12 developed polynomial equations. The F-test resulted in an F statistic value of 0.017 with a significance limit of 0.355 which indicates a statistically significant difference between the use of linear and polynomial equations. The F test value indicates that the polynomial equations display less variance and are therefore a better fit for the data. Table 4 presents the comparison of polynomial and linear error rates for the 12 developed polynomial equations.

Table 3. Results of Laboratory Calibration for EC-20 Soil Moisture Sensor

Soil Class	Field	Depth (cm)	Regression Equation (x = raw counts)	Adjusted R^2	Range in Volumetric Water Content	Abs Error (m^3/m^3)
Sand	3	61	$4.97E\text{-}04x - 3.04E^{-01}$	0.992	0.004-0.36	0.009
Sand	5	61	$4.14E\text{-}04x - 2.73E^{-01}$	0.940	0.004-0.34	0.017
Sand	8	61	$4.38E\text{-}04x - 2.73E^{-01}$	0.986	0.004-0.30	0.017
Sandy Loam	3	20	$5.23E^{-07}x2 - 7.51E^{-04}x + 2.97E^{-01}$	0.950	0.008 - 0.41	0.019
Sandy Loam	4	61	$Neg\ (8.72E^{-09}x2 + 5.21E^{-04}x - 3.01E^{-01})$	0.995	0.02-0.33	0.006
Sandy Loam	7	61	$2.17E\text{-}07x2 - 7.98E^{-05}x - 2.44E^{-02}$	0.987	0.002-0.31	0.011
Sandy Loam	8	20	$2.30E^{-07}x2 - 1.31E^{-04}x + 1.58E^{-03}$	0.991	0.004-0.38	0.010
Silt Loam	1	61	$4.13E^{-04}x - 3.10E^{-01}$	0.880	0.004-0.38	0.031
Loam	2	61	$4.57E^{-07}x2 - 6.31E^{-04}x + 2.40E^{-01}$	0.991	0.004-0.37	0.011
Loam	4	20	$1.73E^{-07}x2 - 3.05E^{-05}x - 4.42E^{-02}$	0.994	0.002-0.36	0.007
Loam	5	20	$1.43E^{-07}x2 + 3.21E^{-05}x - 7.47E^{-02}$	0.998	0.008-0.44	0.005
Loam	7	20	$1.87E^{-07}x2 - 4.27E^{-05}x - 4.59E^{-02}$	0.996	0.004-0.37	0.006
Clay Loam	1	20	$2.99E^{-07}x2 - 1.60E^{-04}x - 1.73E^{-02}$	0.982	0.008-0.40	0.015
Clay Loam	6	20	$3.88E^{-07}x2 - 4.58E^{-04}x + 1.42E^{-01}$	0.991	0.006-0.41	0.008
Clay Loam	6	61	$5.05E^{-07}x2 - 7.12E^{-04}x + 2.65E^{-01}$	0.991	0.008-0.41	0.012
Clay	2	20	$4.49E^{-07}x2 - 6.21E^{-04}x + 2.48E^{-01}$	0.992	0.03-0.45	0.011

Table 4. Comparison of Accuracy for Linear and Polynomial Equations

Soil Class	Calibration	Field	Depth (cm)	Abs Error (m^3/m^3) Polynomial Eq	Abs Error (m^3/m^3) Linear Eq
Sandy Loam	Lab	3	20	0.019	0.033
Sandy Loam	Lab	4	61	0.006	0.006
Sandy Loam	Lab	7	61	0.011	0.015
Sandy Loam	Lab	8	20	0.010	0.020
Loam	Lab	2	61	0.011	0.044
Loam	Lab	4	20	0.007	0.132
Loam	Lab	5	20	0.005	0.040
Loam	Lab	7	20	0.006	0.036
Clay Loam	Lab	1	20	0.015	0.030
Clay Loam	Lab	6	20	0.008	0.034
Clay Loam	Lab	6	61	0.012	0.048
Clay	Lab	2	20	0.011	0.035

Factory Equation

When applied to the laboratory data the standard factory equation resulted in significantly less error than the field calibration equations but more error than the laboratory calibration equations. Table 5 displays the results of applying the factory calibration equation to the lab data. Figure 4 through 7 display the factory calibration applied to the field and lab data respectively. The field calibration data exhibited a significant spread

(Figures 4 and 5) with extremely high errors when compared to the factory equation and therefore the factory equation was applied to the laboratory data.

Table 5. Results of Factory Calibration Equation for EC-20 Soil Moisture Sensor

Soil Class	Field	Depth (cm)	Abs Error (m^3/m^3)
Sand	3	61	0.059
Sand	5	61	0.044
Sand	8	61	0.045
Sandy Loam	3	20	0.036
Sandy Loam	4	61	0.070
Sandy Loam	7	61	0.104
Sandy Loam	8	20	0.067
Silt Loam	1	61	0.043
Loam	2	61	0.045
Loam	4	20	0.039
Loam	5	20	0.041
Loam	7	20	0.035
Clay Loam	1	20	0.032
Clay Loam	6	20	0.044
Clay Loam	6	61	0.044
Clay	2	20	0.042

The absolute error between the factory equation and lab results ranged from 0.032 to 0.104 m^3/m^3 with an average absolute error of 0.049 m^3/m^3 for the 16 soil samples. For loam the factory equation collectively showed the lowest average absolute error of 0.039 m^3/m^3. The average absolute errors by soil texture for sand, sandy loam, and clay loam were 0.049 m^3/m^3, 0.069 m^3/m^3, and 0.040 m^3/m^3. For silt loam and clay only one sample of the soil texture was collected and the absolute error for these was 0.043 m^3/m^3 and 0.042 m^3/m^3 respectively. The four equations that exhibited the largest absolute error were Field 7 61 cm with 0.104 m^3/m^3, Field 4 61 cm with 0.070 m^3/m^3, Field 8 20 cm with 0.067 m^3/m^3 and Field 3 61 cm with 0.059 m^3/m^3. The factory equation on average under predicted for sand soil by 0.037 m^3/m^3 and 0.0061 m^3/m^3 for sandy loam soils. For silt loam, loam, clay loam, and clay the factory equation on average over predicted the soil moisture content by 0.033, 0.029, 0.015, and 0.023 m^3/m^3 respectively.

DISCUSSION

The results obtained during this study provide insight into the two calibration methods and the differences to the standard factory calibration equation. Field calibration of the EC-20 sensor is the least desired calibration method and exhibits the largest error rates and scatter in data. The fact that significant scatter was observed can be attributed to the field calibration techniques. It was found that field calibration of the EC-20 sensor is limited due to variations in sampling locations which are caused by voids and varying root densities, even though the soil type was similar. Even though the sampling locations were adjacent to the EC-20 probe this is not the same as being co-located. Other limitations for field calibration which were observed during this study and by Kaleita et al (2005) were organic residues such as roots, worm holes, variations in field bulk density and the destructive and time consuming nature of the gravimetric sampling. The average adjusted r^2 values for the field calibration of 0.558 agree well with average values of 0.77, 0.69 and 0.74 obtained by Kaleita et al. (2005), Polyakov et al. (2005), and Leib et al. (2003) for field calibrations. Although none of the fields exhibited an EC higher than 5.23 dS/m there is the possibility that the field calibrations were influenced by variations in salinity during the irrigation season and this issue merits further investigation. It was also found that probe failure in the field led to collected gravimetric data that could not be correlated to a probe output, which limited the amount of data available for developing field calibration equations. On several occasions sensors failed due to water intrusion on the circuit boards and gophers gnawing on the cables, and shorting them out which reduced available data.

The error rates obtained using the field calibration methods are extremely high and it would not be possible to accurately measure the amount of water added or depleted using the field calibration equations. Although we attempted to schedule field sampling to cover a wide range of moisture contents, it was not possible to collect data at saturation or wilting point due to farmer irrigation practices. We therefore advise against using field calibrations for the EC-20 sensor and suggest performing the laboratory calibration presented here.

Our findings support that laboratory calibration is an accurate method to calibrate the EC-20 soil moisture sensor. The average adjusted r^2 value for the laboratory equations of 0.979 is significantly higher than the average adjusted r^2 value of 0.558 obtained from the field calibration. A high coefficient of determination indicates that the variability in the data is being explained adequately and our results for adjusted r^2 using the laboratory method compare favorably to the results of other researchers performing laboratory calibration equations for capacitance sensors. Kaleita et al. (2005) were able to obtain r^2 values of 0.85 and Polyakov et al. (2005) obtained values of 0.96 using laboratory calibration on capacitance sensors. The limited studies specific to the EC-20 have resulted in similar r^2 values with Nemali et al. (2007) finding r^2 values of 0.95 for 9 soilless substrates. Using a similar sensor, the ECH2O EC-5, Sakaki et al. (2008) were able to obtain r^2 values of 0.97.

The error rate observed indicates that the development of laboratory calibration equations can result in accurate measurement of soil moisture content. Our error rates agree well with Bosch (2004), who found that using laboratory equations, error rates for the EC-10 and EC-20 in sandy coastal soil were $0.05 m^3/m^3$. Polyakov et al. (2005) found that the error rates were greatly reduced using laboratory calibrations in favor of field calibrations. Our findings also corroborate the results of Paltineanu and Starr (1997) that the most accurate calibration is achieved in the laboratory.

The method of using a calibration cylinder results in accurate laboratory equations due to the ability to replicate field bulk density. The use of a single probe in the laboratory calibration to represent the behavior of other probes is also appropriate. Statistical analysis has shown that there is no significant difference in the measurements of individual ECH20 Probes (Kizito et al. 2008; Sakaki et al. 2008; Nemali et al. 2007), and therefore probe specific calibrations were not required. We recommend that laboratory calibrations of capacitance sensors be completed using the procedure outlined here as replicating bulk density in the lab to bulk density found in the field is crucial to developing accurate equations (Mitsuishi and Mizoguchi, 2007; Starr and Palineanu, 2002). In addition to ensuring accuracy the method acceptably replicates field conditions so that minimal distortion occurs and the developed equations can be applied to collected field data.

The results obtained during this study indicate that the factory equation accuracy is dependent on soil type. The underprediction of soil moisture content in sand and sandy loam soils we observed was also found by Plauborg et al. (2005) for a different capacitance sensor. In one of the few studies done using the EC-20, Bosch (2004) found that the factory calibration equation consistently underpredicted the soil water content in three sandy coastal soils as well. For loam, silt loam, clay loam and clay the overprediction using the factory equation corresponds with results found by Inoue et al. (2008) and Polyakov et al. (2005). Both of these studies found that the manufacturer's equations overestimated the actual water content of dielectric soil moisture sensors.

The fact that the factory equation underestimates for sandy soils and overestimates for loam and clay soils indicates that the equation is designed to be used for general applications and is not soil specific. Additionally, the factory equation is linear. We found that the behavior of the EC-20 probe in sandy soils was explained by a linear equation but that for loam, silt loam, clay loam, and clay the behavior was characterized by second order polynomial curves. This is consistent with the finding of other researchers (Bandaranayake et al. 2007; Kaleita et al. 2005; Plauborg et al. 2005; Fares et al. 2004; Paltineanu and Starr, 1997; Gaudo et al. 1993). Although the factory equation is general we found that the accuracy of 0.04 m^3/m^3 without calibration suggested by the manufacturer was replicated in our study. Based on this finding, we suggest using the factory calibration equation in studies where extremely low error rates are not required. For all other studies such as precision irrigation, we recommend completing a laboratory calibration in favor of a field calibration due to the reasons mentioned previously.

During the installation of the EC-20 probes and the subsequent monitoring and data collection, much information was gained that will be useful to other researchers using similar equipment. We found that the installation of the Em5B datalogger on a T-post should be carried out using wire and not the factory supplied zip ties. Due to the extreme sunlight present in New Mexico, the zip ties were exposed to UV and became brittle and snapped in as little as two months. We also found that it was critical to use the factory supplied installation toolkit to ensure that sensors were not damaged during installation. Additionally, using the factory supplied auger was also crucial as the hole created is small and limits the amount of root damage. We recommend that the EC-20 sensors should be sealed at the interface between the probe and the lead wire with an extra layer of silicone before being installed to prevent water intrusion. If sensors are deployed away from the border of the field and longer cables are necessary, we suggest purchasing the correct length already set from the factory. This eliminates having a wire junction buried in the field which can lead to water instruction, electrical shorts, and erroneous sensor outputs. Finally, the sensors locations should be monitored and data downloaded continuously due to failure caused by gophers chewing on cables, other animals, and possible mechanical damage to dataloggers during normal field operations. Being diligent about monitoring the installation sites will prevent the loss of valuable data. One option that has recently become available for downloading data is the use of radio telementry and this offers the ability to remotely monitor installation sites. Although costly, this approach provides real time data that can be used for precise irrigation scheduling and warrants future study and implementation.

CONCLUSION

The study of the ECH2O EC-20 soil moisture probe in soils of the Middle Rio Grande Valley has shown that field calibration of the probe should be substituted for a laboratory calibration method. Through the completed study, it was possible to develop 16 accurate laboratory calibration equations for the ECH2O EC-20 soil moisture sensor. The modified laboratory calibration method used in the equation development provides researchers with a method that manages the bulk density to replicate field conditions and develops accurate equations. It is our hope that the laboratory calibration method presented here assists researchers in obtaining more precise calibration equations. Additionally, calibration equations for 16 EC-20 installations are presented which can be used by researchers in the Middle Rio Grande Valley and elsewhere with similar soil textures.

Through the use of lab calibrated EC-20 soil moisture sensors, it will become possible to precisely schedule irrigation events based on crop water requirements, which can reduce water use by up to 40% (Oad et al. 2009; Oad and Kullman 2006). In the Middle Rio Grande this is extremely crucial. The use of these sensors offers the ability and opportunity to increase water use efficiency through irrigation scheduling and ensure the sustainability of agriculture in the Middle Rio Grande Valley as interstate compacts and Endangered Species Act issues limit water available to agriculture during drought.

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PERFORMANCE ASSESSMENT OF KRISHNA WESTERN DELTA USING REMOTE SENSING — A CASE STUDY

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ABSTRACT

The Krishna delta irrigation system, one of the earliest major irrigation projects in southern India was designed by Sir Arthur Cotton during in the middle of 19th century on river Krishna near Vijayawada. The project irrigates an ayacut of 5.14 lakh hectares covering West Godavari, Krishna, Guntur and Prakasam districts of Andhra Pradesh. Using multi-date satellite data of Krishna Western Delta (KWD), flow information, crop cutting experiment (CCE) plot data of the State Department of Agriculture (SDA) and AP Water Management (APWAM) Project obtained during kharif 2005-06, performance indicators were computed and performance of irrigation system was assessed.

Paddy was the major crop gown in KWD. Hence paddy yield model was developed using ground obtained CCE plot yield data and satellite derived normalized difference vegetative index (NDVI). Very good correlation (r = 0.7) was obtained between these parameters. Hence, it was extrapolated to the entire KWD belt. The average yield of KWD derived based on NDVI observations was closely matched with the yield data of APWAM and SDA. Highest efficiency (85%) was obtained in highlevel canal command. The lower efficiency obtained in Kommamur was due to poor condition of the canal, high conveyance losses and release of excess rain water in to the sea through the canal. The productivity of water was varying from 0.7 to 1.0 kg m^{-3} across KWD except in Kommamur which had only 0.5 kg m^{-3}.

The information on nature, extent and distribution of salt affected soils and waterlogged areas in KWD was generated based on visual interpretation of FCC imageries obtained from space-borne remote sensing satellites. It was computed that about 18,102 and 4,675 hectares of area was salt affected and waterlogged, respectively.

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INTRODUCTION

Satellite provides a convenient platform to observe earth features which capable of giving spatial data which is continuous in nature. Space-borne multi-spectral data by virtue of synoptic coverage of a fairly large area at regular interval are very useful in generating information on the status of irrigation commands at different time intervals for assessing performance evaluation. Hence it can be used as a tool to collect data in any irrigation command viz. cropping pattern, crop condition, crop productivity, problems of water logging and soil salinity etc. The capabilities of the technology has been proved through various studies on irrigated commands across the world by generating the information that is crucial for restoration or rehabilitation or to evaluate the performance of the system.

The objective of the study is to evaluate overall performance of irrigation system in Krishna Western Delta. Irrigation performance assessment is the systematic spatial and temporal evaluation of irrigation systems to diagnose problems. A common approach is to calculate irrigation performance indicators using remote sensing and field data. Performance evaluation of Krishna western Delta irrigation system in Andhra Pradesh State for the Kharif season of the year 2005-2006 was taken up based on various performance indicators. Multi-date satellite data of Krishna Western Delta (KWD) irrigation command during Kharif season 2005-06 are analyzed for irrigation performance assessment.

Performance evaluation of irrigation command involves knowledge of both the total demand and the distribution of demand for irrigation water over space and time. The major information required for irrigation studies is about crop types, acreages, condition and yield. From this information statistical estimates of water demands can be made. Because of the vast areas involved, time constraints and dynamic changes, remote sensing is found to be an effective tool for irrigation studies compared to conventional methods which are point based, time consuming.

Paddy yield model was developed in this study using ground observed CCE plot yield, satellite derived NDVI during 2005-06 kharif season. This has been used to extrapolate the yield for entire KWD.

In the present study, various performance indicators useful for the irrigation performance assessment of Krishna Western Delta using satellite data and flow information, CCE plot experiment data were carried out. This study has given wealth of information about KWD performance indicators.

Description of Krishna western delta study area

Location and climate**:** The Krishna Western Delta (Krishna main canal command) covers Guntur district and a small part of Prakasam district in the state of Andhra Pradesh (Figure 1). The Krishna Western Delta (KWD) has a command area of approximately

242,000 hectares. KWD covers the districts of Guntur (210,000 ha) and Prakasam (32,000 ha).

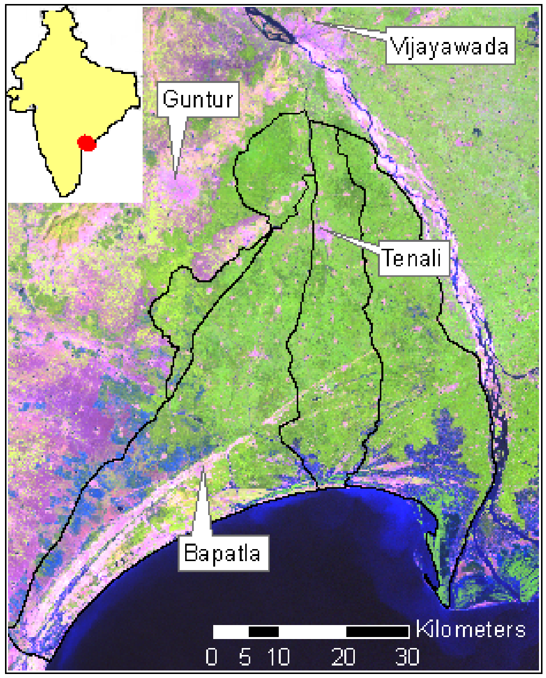

Figure 1. Krishna western Delta study area (command boundaries in black lines)

The climate of the Krishna Western Delta is dominated by the southwest monsoon which provides most of the precipitation for the region. The mean annual rainfall amounts to 800 - 900 mm, and about 90% of the rainfall is received during the monsoon months of May to October. The climate can be classified as sub-humid, with minimum and maximum average temperatures ranging from 12.8 to 26.0 °C and 29.7 to 46.5 °C respectively (Srinivasulu et al., 2003).

MATERIALS AND METHODOLOGY

Irrigation performance assessment

Irrigation efficiency is one of the most important indicators to determine the performance of an irrigation scheme. However, efficiency alone is not a sufficient indicator to define and improve the performance of an irrigation system. The concept of efficiency depends upon scale, and can be misleading (Bos et al, 2005; Jacobs et al, 2006). What is considered as "losses" at a certain scale can be a source of water at another scale. For instance, percolation "losses" at field level contribute to a recharge of the aquifer and this water can be recovered later. Such recycling can result in high overall efficiencies.

A general accepted figure for field scale irrigation efficiency is 45%, while efficiency regarded from the river basin as a total system (with recycling of percolated water) can be as high as 80 to 100% (Bastiaanssen et al., 2003). These scale considerations are often disregarded, and improvements in on-farm irrigation efficiency are expected to result in additional water supply for other districts.

Efficiency assessments should therefore be accompanied with water productivity studies, which implies a more “basin wide” assessment of water use. The International Water Management Institute (IWMI) has started a strong lobby to change the nomenclature from water use efficiency into water productivity, which is now also followed by other Consultative Group on International Agricultural Research (CGIAR) institutes and the Food and Agricultural Organization of the United Nations FAO (Bastiaanssen et al., 2003).

In the Krishna Western Delta study the following performance issues are assessed:

- Uniformity of water application;
- Spatial distribution of crop yields
- Effect of salinity on crop yields
- Irrigation efficiency
- Productivity of water

Satellite images and field data are used to calculate GIS based irrigation performance indicators. Performance indicators are partly selected from the handbook on irrigation performance assessment (Bos et al., 2005).

Performance Indicators

Uniformity of water application: The uniformity index (UI) refers to the variation (or non-uniformity) in the amounts of water applied to locations within the irrigated area and is defined as:

$$\mathrm{UI}\,(\text{-}) = \frac{V_i \,/\, A_i}{V_j \,/\, A_j}$$

Where:

V_j = total irrigation volume supplied to KWD (m^3);
V_i = irrigation volume measured at the head intake of command *i* (m^3);
A_j = total irrigated area KWD (ha);
A_i = irrigated area in command *i* (ha).

Irrigation efficiency**:** The Overall Command Efficiency refers to the degree in which water supply and water demand are matched. The indicator assesses irrigation efficiency at command area scale, since irrigation volumes are only measured at the head intake of each main command. The Overall Command Efficiency (OCE) is defined as:

$$OCE\,(\text{-}) = \frac{(WR_{command,i})}{(WS_{command,i})}$$

Where:

$WR_{command,\,i}$ = Irrigation Water Requirement at command *i* (mm);
$WS_{command,\,i}$ = Irrigation Water Supply at command *i*, measured at head intake (mm).

First the irrigation water requirement for rice at field level (net irrigation requirement, WR_{field}) is determined as:

$$WR_{field}\ (mm) = (ET_p - P_e) + LP$$

Where:
ET_p = Potential Evapotranspiration from transplanting to harvest (mm)
P_e = Effective rainfall (mm)
LP = Land Preparation and nursery demand (mm)
Consequently the irrigation requirement at command intake level (gross irrigation requirement, $WR_{command}$) is determined as:

$$WR_{command,i}\ (mm) = \frac{WR_{field}}{C * P}$$

Where:
WR_{field} = Water demand at field level (mm)
C = Correction factor for conveyance efficiency (-).
P = Correction factor for field application efficiency (-)
The overall command efficiency ratio is calculated both on a seasonal basis as well as on a monthly basis.

Water productivity**:** The water productivity indicator quantifies the yield per volume of irrigation water supplied. Comparing this indicator for different command areas illustrates the spatial variation in productivity.
The Water Productivity (WP) is defined as (Molden et al., 1998):

$$WP\ (kg/m^3) = \frac{Y_{command,i}}{V_{command,i}}$$

Where:
$Y_{command,\ i}$ = Rice yield in command *i* (kg);

$V_{command,\ i}$ (m3). = Irrigation volume measured at the head intake of command *i*

To assess yield performance, WP results should be related to the intended (target) yields for the KWD area. The WP values should however not be compared to WP levels in other regions or for different seasons, as they are heavily influenced by local climate.

Temporal and spatial assessment of irrigation

Temporal assessment**:** The assessment is done for the Kharif season of 2005. Uniformity and productivity are assessed on a seasonal basis while efficiency is also addressed on a monthly basis.

Spatial assessment**: Since** irrigation water is controlled up to the main command level (i.e. water volumes are available at the head intake of the command areas), performance indicators are calculated at command level, and no differentiation *within* the commands was possible.

Data acquisition

Remote Sensing data: The Indian Resourcesat-1 Satellite (IRS P6) LISS III sensor (Linear Imaging and Self Scanning) was used for the study. Resource sat – 1 is especially designed for integrated land and water management and agricultural applications.

The Krishna Western Delta is covered by one IRS image and is referenced as path 102, row 61/62 (row 61 with 50% shift downwards). Figure 2 shows an IRS footprint to illustrate the Krishna Western Delta's coverage.

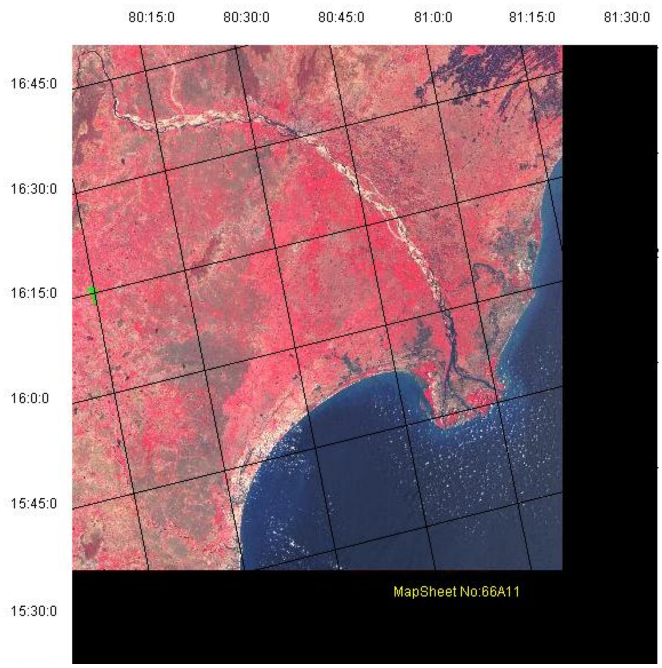

Figure 2. Footprint IRS P6 LISS III K W D, path 102, row 61 (50% shift South)

Selection of dates**:** Because of the large spreading in rice transplanting during Kharif, two images were acquired, representing the vegetative (September) and reproductive/ripening stage of rice (November).In August the cloud coverage was very high, so this month was excluded from the analysis. For salinity assessment, one image was selected in April 2006, where most of the land is fallow. The following set of IRS P6 LISS3 data were obtained from NRSA for 2005/2006 (Table 1).

Table 1. IRS P6 LISS III images

No.	Date	Purpose
1	27 September 2005	Vegetative stage rice
2	14 November 2005	Ripening stage rice
3	07 April 2006	Salinity assessment

Field campaigns: During the time of satellite overpass, three field campaigns were organised by ANGRAU to collect field data. For the crop yield assessment, a number of 60 sample points were identified in Krishna Western Delta using a GPS (Figure 3). The sample points represent the head, middle and tail reaches of KWD and covers various land uses (rice, other crops and fallow land). For salinity assessment, a number of 57 soil samples were taken.

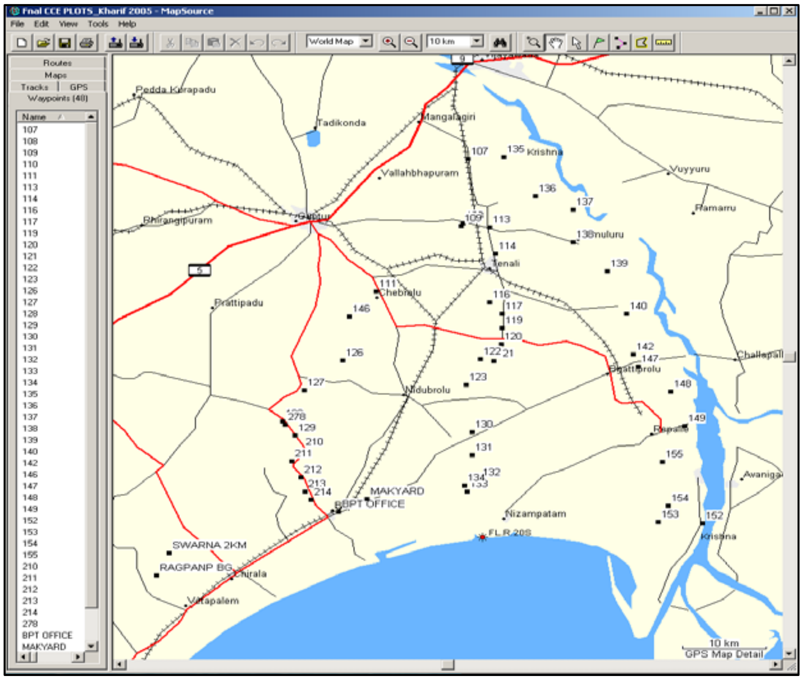

Figure 3. Location of sample points for crop mapping Krishna Western Delta

RESULTS AND DISCUSSION

Classification

A supervised classification was performed, where pixels were clustered into classes using the ground truth information. The planting of rice progresses over a large period of about 1 to 1.5 month on a continuous basis, from July to September. Therefore categories of rice stages (early-mid-late) were made, based on the collected field data. From these categories, reflectance characteristics (“signatures”) were extracted which formed the classes to perform the supervised classification (Table 2 & Figure.4).

Table 2. Pre-defined classes for supervised classification

Class name	Class description
Rice Early	Crop planted between July 20 and August 10
Rice Mid	Crop planted between August 11 and August 31
Rice Late	Crop planted after 1st September
Annual crops	Includes irrigated crops other than rice such as banana, sugarcane, turmeric, chillies.
Prawn	Prawn cultivation
Mangroves	Mangrove cultivation
Waterlogged	Waterlogged areas (water ponding on surface)*

* From remote sensing only waterlogged areas can be detected with standing water on the surface.

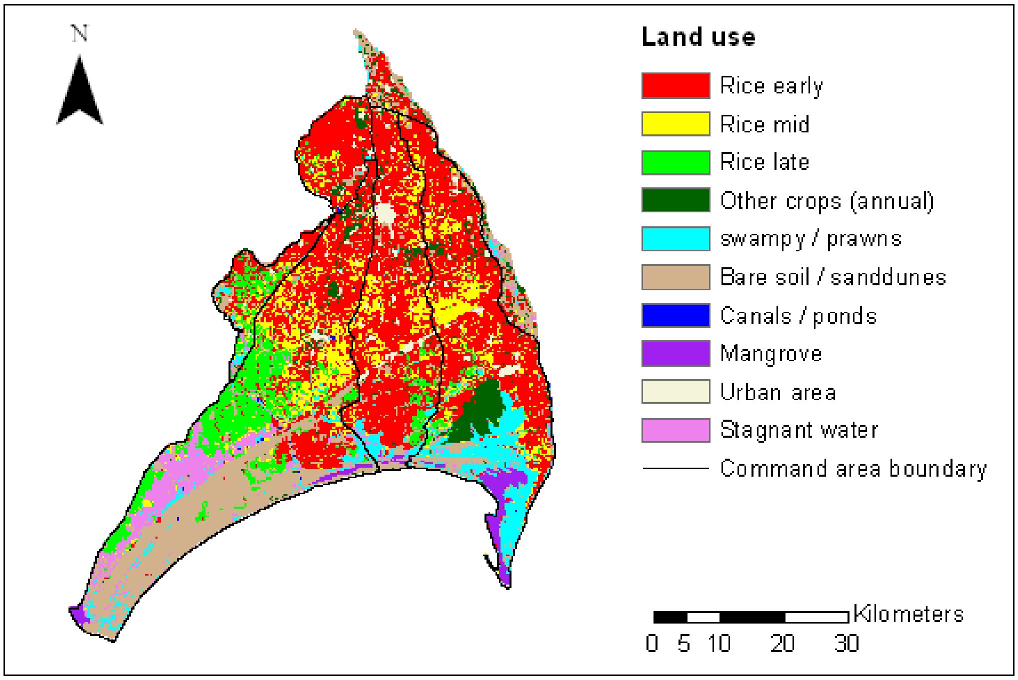

Figure 4. Crop map Krishna Western Delta, Kharif 2005

As can be seen from the figure 4. lowest irrigation intensities appear at the tail ends of the command areas. Further, one can distinguish a general trend from head to tail. Rice crop was sown at early stages appear mostly in the head part of the delta, whereas late sown rice is found at the tail end part. An exception is found in the most southern part of the delta (tails ends of the Nizampatnam canal), where rice is sown at early stages.

Crop yield map: A crop yield map was created from the established yield model (Figure 5). Total yields for the command areas are summarized in Table 3.

Table 3. Rice yields in the KWD commands (Kharif 2005)

	Rice cultivation (ha)	Average rice yield (t/ha)	Production (tons)	Yield variation (spatial coefficient)
C1 KWB Canal	45,698	5.0	230,442	0.61
C2 Nizampatnam	42,252	5.2	217,769	0.68
C3 Kommamur	57,300	5.3	300,965	0.68
C4 High Level Canal	12,381	5.4	67,155	0.56
C5 AM Channel	8,803	5.4	47,371	0.60
Total KWD	166,435	5.2	863,701	-

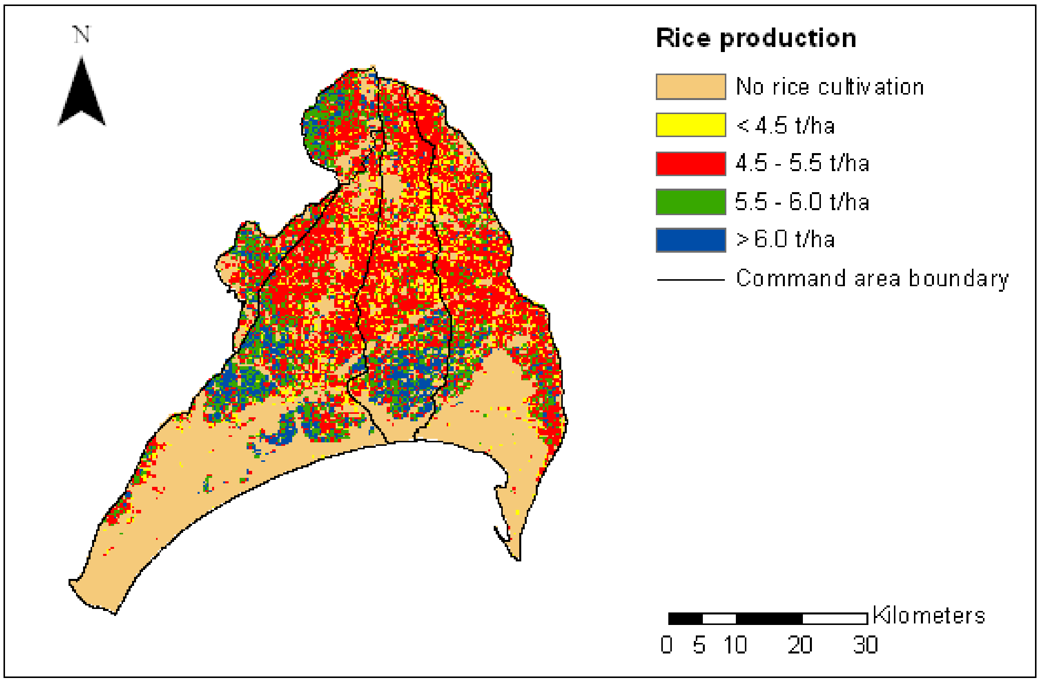

Figure 5. Spatial variability of rice yield in Krishna Western Delta (Kharif 2005)

Irrigation water requirements

Net irrigation requirements: The CRIWAR model (Bos et al, 1996) was used to determine the crop water requirements. Crop water requirements are defined here as net irrigation requirements, quantified as the difference between the potential evapotranspiration and (effective) precipitation. It refers to the amount of irrigation water needed at field level, without any corrections for field application efficiency.

Meteorological records from two weather stations located in the study area were used: (i) Bapatla meteo station and (ii) Lam meteo station, located near Guntur. The meteorological stations are approximately 45 km apart and represent two different climatic regions.

The CRIWAR model does not include the land preparation and nursery phase for rice. Water requirements for this phase are estimated as 200 mm for land preparation and 50mm on 1/20 of the rice area for growing nurseries. These numbers are based on local experience. The net irrigation requirements for the different command areas are presented in Table 4.

Table 4 Irrigation requirements, Kharif 2005

Command area	PotentialEvapotranspiration ETp (mm)	Net irrigation requirements (mm) (ETp-Pe)
C1 Krishna Western Bank	710	215
C2 Nizampatnam	711	211
C3 Kommamur	690	238
C4 High Level canal	707	199
C5 AM channel	681	229

Figure 6 shows the variability within the Kharif season of precipitation, irrigation and potential evapotranspiration for the total Krishna Western Delta.

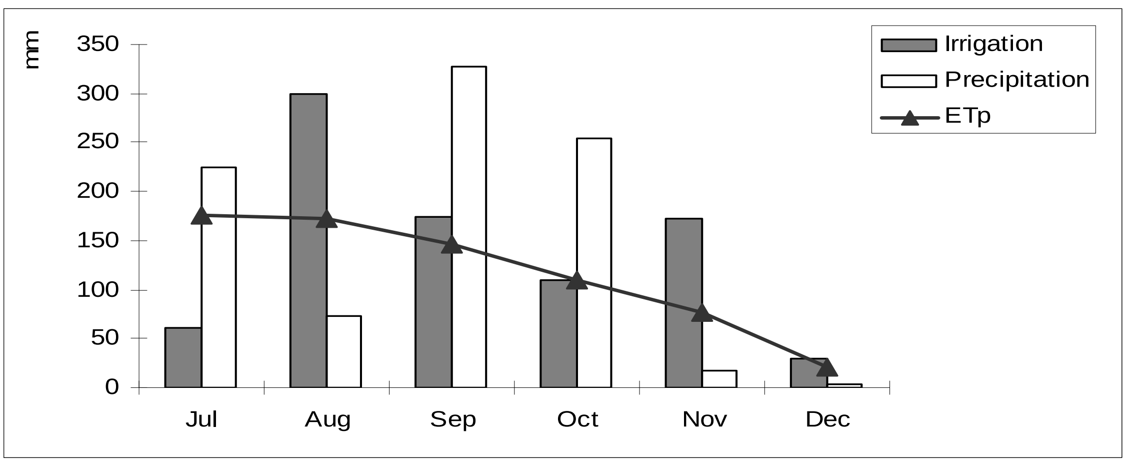

Figure 6. Seasonal variability of precipitation, irrigation and potential evapotranspiration (ETp) in mm for KWD, Kharif 2005

Gross irrigation requirements**:** To convert net irrigation requirements to gross irrigation requirements, a correction for field application (percolation) and conveyance was made. For field application, an efficiency of 60% was used for the KWD area (Srinivasulu, 2003). For conveyance losses, an efficiency of 70% was maintained. The efficiency percentages were confirmed by the Irrigation Department.

Performance assessment

Performance indicators: Table 5 summarises the irrigation supplies, irrigated areas, irrigation requirements and rice yields, from which the performance indicators were calculated and presented in Table 6.

Table 5. Overview irrigation data KWD commands

	Irrigation (mm)	Rice area (ha)	Rice intensity ** (%)	Gross irrigation requirements (mm)*	Rice yield (kg)	Average yield (t ha-1)
C1 KWB	757	45,698	87	512	230,441,600	5.0
C2 NIZ	660	42,252	97	503	217,768,796	5.2
C3 KOM	1135	57,300	96	566	300,965,171	5.3
C4 HLC	557	12,381	92	475	67,154,487	5.4
C5 AMC	738	8,803	97	544	47,370,539	5.4

* Gross irrigation requirements are defined as (ETp – Pe), corrected for application and conveyance
** Rice intensity refers to rice cultivation as a percentage of irrigated area

It was estimated that 26% of the water required for land preparation and for growing nurseries needed to be supplied by canal water; according to the rice staggering dates the remaining part could be met from rainfall.

Table 6. Performance indicators at KWD command area scale, Kharif 2005

Command name	Uniformity index (-)	Overall Command Efficiency (-)	Water productivity (kg/m3)
C1 Krishna Western Bank	0.9	68	0.7
C2 Nizampatnam	0.8	76	0.8
C3 Kommamur	1.3	50	0.5
C4 High Level Canal	0.7	85	1.0
C5 AM Channel	0.9	74	0.7

Uniformity (spatial variability in canal water supplies)**:** Comparing the different command areas, it can be seen from the uniformity index that water was distributed in a fairly uniform way. This means that the command areas received similar volumes of water for each hectare. An exception is Kommamur command, which received an excessive amount of water.

It should be noted that equity of water distribution *within* the command area (head- and tail-reach) could not be quantified. This is because the irrigation volumes are available at command level (head intake) only.

Overall command irrigation efficiency: On a yearly basis, the average irrigation efficiency at command level is 71%, which is reasonable. A correction was already applied for water that will not reach the fields due to conveyance and percolation, indicating that the remaining 29% of the water which was not efficient was drained into the sea or was stored in ponds.

Irrigation efficiency was highest in the High Level Canal command, which means that here the best match between irrigation demand and supply was found. Lowest efficiency was found in Kommamur, where about twice the amount needed was supplied to crops. Part of the irrigation water was directly drained from Kommamur canal.

On a monthly basis, the five commands showed similar variations within the Kharif season (Figure 7). Water supply matched water demand fairly well except for the cyclone months of September and October, where severe over-irrigation took place. In these months the rainfall fulfilled the crop water demand, and no irrigation was needed. The reason for the over-irrigation in this period is that the maximum capacity of Prakasam barrage is reached in the months of September – October. Excess water cannot be stored in this period and needs to be released (spilled) from the barrage. It is a political decision to spill the excess water through the canals, instead of directly to sea.

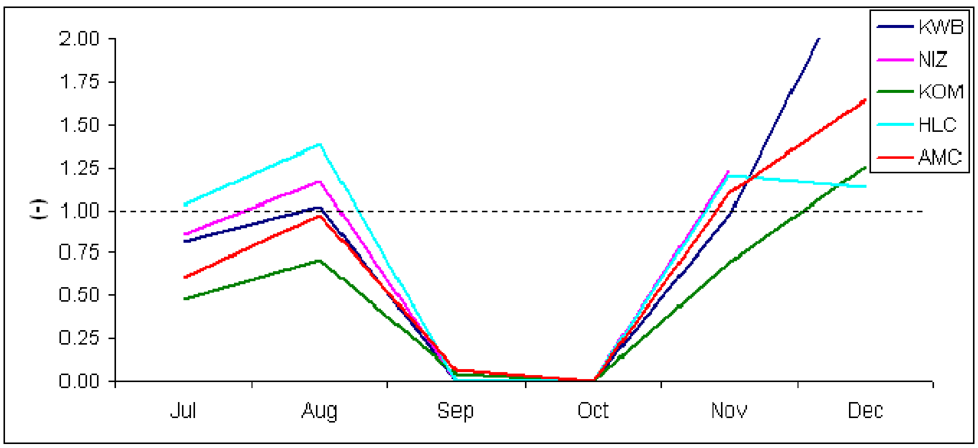

Figure 7. Monthly variability in irrigation efficiency (-) KWD commands, Kharif 2005

Water productivity: Water productivity levels were fairly high within the KWD command, except for Kommamur command (0.5 kg/m^3). The low productivity in Kommamur can be explained by the supply of excess water, hampering probably crop production as well.

Distribution of salt affected Soils

The study also revealed the distribution of salt affected soils in the five distributory command areas of the delta area. The distribution of salt affected soils is given in Table. 8 and depicted in Figure 8

Table 8. Area statistics of salt affected soils in different commands (in hectares)

Category	K W Bank command (C1)	Nizam. east command (C2)	Nizam. west command (C3)	Komm. command (C4)	A M channel command (C5)	Total
Slightly saline	65.78	--	--	1896.88	30.13	1992.79
Moderately saline	5352.70	407.54	156.83	2094.70	877.45	8889.21
Strongly saline	6199.05	1.29828	289.26	730.16		7219.77
Total	11617.54	408.84	446.09	4721.74	907.59	18101.79

From the above table it is evident that the occurrence of saline soils was more in Krishna western bank command (11618 ha) followed by Kommamur command (4722 ha).

Water logging

In the study area water logging is observed along the canals and in swale complex regions. Satellite data enabled to map only the surface water logging. An area of 4675 hectares was found to be waterlogged (Table 9). The spatial extent of waterlogged areas is given in the table below.

Table 9. Area statistics of waterlogged areas in different commands (in hectares)

Category	K W Bank command (C1)	Nizam. east command (C2)	Nizam. west command (C3)	Komm. command (C4)	A M channel command (C5)	Total
Water logging with salinity	---	----	----	718.24	----	718.24
Waterlogged	380.96	707.40	----	2868.98	---	3957.35
Total	380.96	707.40		3587.22		4675.59

Besides the problem of water logging and salinity occurrence of saline soils noticeable area (3892 hectares) is under mangroves which are strongly saline.

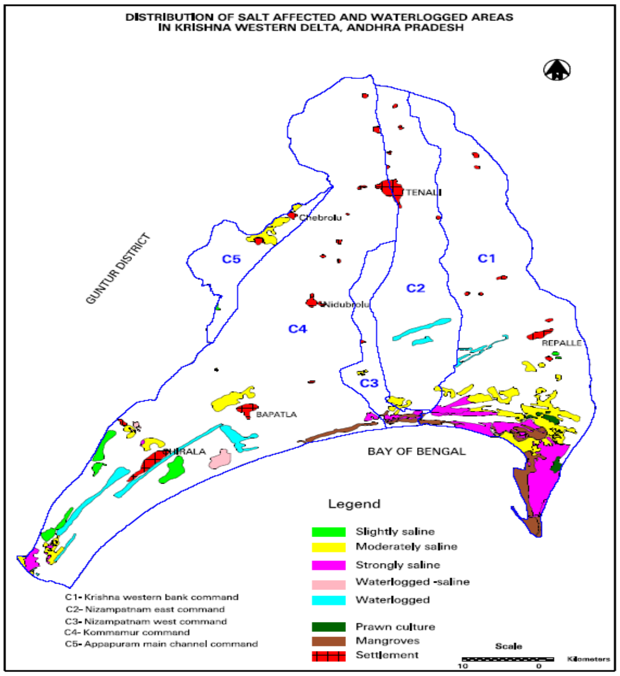

Figure 8. Salt affected and waterlogged areas in KWD

<u>Effect of Water Logging and Soil Salinity on Irrigation System Performance:</u> It was observed that the water logging and soil salinity exists in tail ends of Kommamur canal command where it is coinciding with paddy area. It is estimated from paddy crop mask during 2005-06 that 6200ha is under water logging and soil salinity. This is only 2% of the total ayacut under Krishna Western Delta. This may not influence the irrigation system performance in total, however, these areas need attention for reclamation measures and avoid further degradation.

CONCLUSIONS

The Krishna Western Delta case study demonstrates the use of satellite remote sensing for quantifying the irrigated area and productivity in a large irrigation system in India. Irrigation performance indicators were calculated for uniformity, efficiency and productivity.

In the Krishna Western Delta, water was applied at rather uniform levels. An exception appeared to be the Kommamur command, which received a relatively large amount of water.

Through remote sensing, the average rice yield for the Krishna Western Delta was found to be 5.2 t/ha. Average rice yields for the commands were relatively uniform throughout the area and highest variation in yields were found in the Kommamur and Nizampatnam commands. Some clear higher yielding areas were found in the tail reaches, which can be explained by lower irrigation applications than in head reaches, where farmers tend to over-irrigate. The yield model established to estimate the rice yields was found to be reasonable, but could be improved in future studies by adding more field samples and at better locations.

Irrigation at command scale was reasonably efficient for the overall season, however on a monthly basis, there was a mismatch in demand and supply during the cyclone months (September and October). Although sufficient rainfall was available to meet the water demand in this period, a large amount of canal water was supplied. The reason for this is that excess water in this period could not be stored in the Prakasam reservoir and needed to be released (spilled) to sea. For political reasons water is released through the canals, instead of directly to sea.

Comparing irrigation performance in the KWD commands, the best performing command appeared High Level canal, showing highest efficiency (85%) and the largest water productivity (1 kg/m^3). Poor performance was demonstrated by the Kommamur command, with an efficiency of 50% and a water productivity of 0.5 kg/m^3, due to excess irrigation supplies.

A systematic visual interpretation of space borne multi-spectral data enabled generation of information on the nature, extent, spatial distribution of salt affected soils and water logged areas in the Krishna western delta. Salt -affected soils have been found to be associated mostly in the coastal region.

In Krishna Western Delta (KWD) the salt affected soils are categorized into 3 classes of salinity (slight, moderate, strong). About 18101 hectares of salt- affected soils were found to occur in the command area and the satellite data was found to be useful in identification and mapping of surface water logging in Krishna Western delta and they were found in 4675 hectares.

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SOUTH PLATTE WATER CONSERVATION PROJECT
A MUNICIPAL-AGRICULTURAL PARTNERSHIP

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ABSTRACT

Municipal water demand for the Front Range of Colorado is expected to increase substantially over the coming years. As these demands continue to grow, the pressure to dry up agricultural water supplies in the South Platte River basin continues to be more acute. The Northern Colorado Water Conservancy District (Northern Water) along with fifteen municipal water providers is presently in the permitting process for the Northern Integrated Supply Project (NISP). This project will consist of two distinct but integrated pieces – the new 170,000 acre-ft Glade Reservoir located northwest of Fort Collins, Colorado, and the South Platte Water Conservation Project (SPWCP). The SPWCP involves a pump station on the South Platte River which pumps water during the non-irrigation season to the proposed 45,600 acre-ft Galeton Reservoir located northeast of Greeley Colorado. The SPWCP will then deliver water during the summer to two large irrigation companies – the Larimer and Weld Irrigation Company and the New Cache Ditch Company. A like quantity of water that those companies would have diverted under their senior water rights will be exchanged upstream to Glade Reservoir for municipal use. This paper will discuss the formulation of the SPWCP project as well as the partnership that has been formulated with the ditch companies. In addition to an overview of issues associated with NISP, specific issues associated with the exchange with the ditch companies will be presented. In particular, the benefits of the municipal-agricultural partnership will be explained.

BACKGROUND

In April, 1986 a suburban city north of Denver Colorado announced that they had acquired nearly half of the shares of the Water Supply and Storage Company in northern Colorado for their future water supply. While the Arkansas basin in southeastern Colorado has seen the devastation of large-scale irrigated agricultural dry-up, northern Colorado has largely been immune to this type of activity. However, pending the execution of the transfer of these water rights, this action will ultimately dry up 20,000 acres of productive irrigated farm ground, resulting in a direct loss to the northern Colorado economy, and will have a ripple effect throughout the supporting businesses and industries.

In December, 1992, Northern Water engineers posted new water right notice signs throughout the Cache la Poudre River basin announcing Northern Water's intent to file water rights for a new water project called the South Platte Water Conservation Project (SPWCP). This project, instead of relying on agricultural dry-up, would involve a partnership with agricultural water users to keep irrigated farms in production while

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enabling municipal water users to take advantage of the high quality water that the ditch companies have historically been utilizing.

The formulation of the SPWCP was based upon the unique river basin geography in northern Colorado. The Cache la Poudre River (Poudre) flows into the South Platte River near Greeley Colorado. A picture of the river near this location is shown in Figure 1. An overall map of the basin is shown in Figure 2. Specifically, a large portion of the Poudre River basin irrigation lies a short distance from the South Platte River where flows are generally more plentiful, particularly during the winter and spring months. These characteristics make this basin ideal for a water exchange with municipal water users. The challenges are in finding the right infrastructure to enable the South Platte flows to be utilized and developing ditch company partnerships to allow for an exchange to be made between the ditch companies and municipalities.

At the heart of the SPWCP lies a relatively simple concept – divert water from the South Platte River during the winter and spring months, store that water until the irrigation season, release that water to Poudre River irrigation ditches, and exchange the high quality water that those ditches would have diverted higher up in the Poudre system. The project would put water suitable for agricultural use onto irrigated farms, and by exchange, provide high quality mountain runoff water to municipalities. Compensation would be made to the ditch companies and irrigators for the privilege of utilizing their senior water rights and a partnership would be created between the agricultural community and the municipal water users to insure the continued use, and therefore, the continued exchange of this new water supply.

Figure 1. South Platte River Near Greeley, Colorado

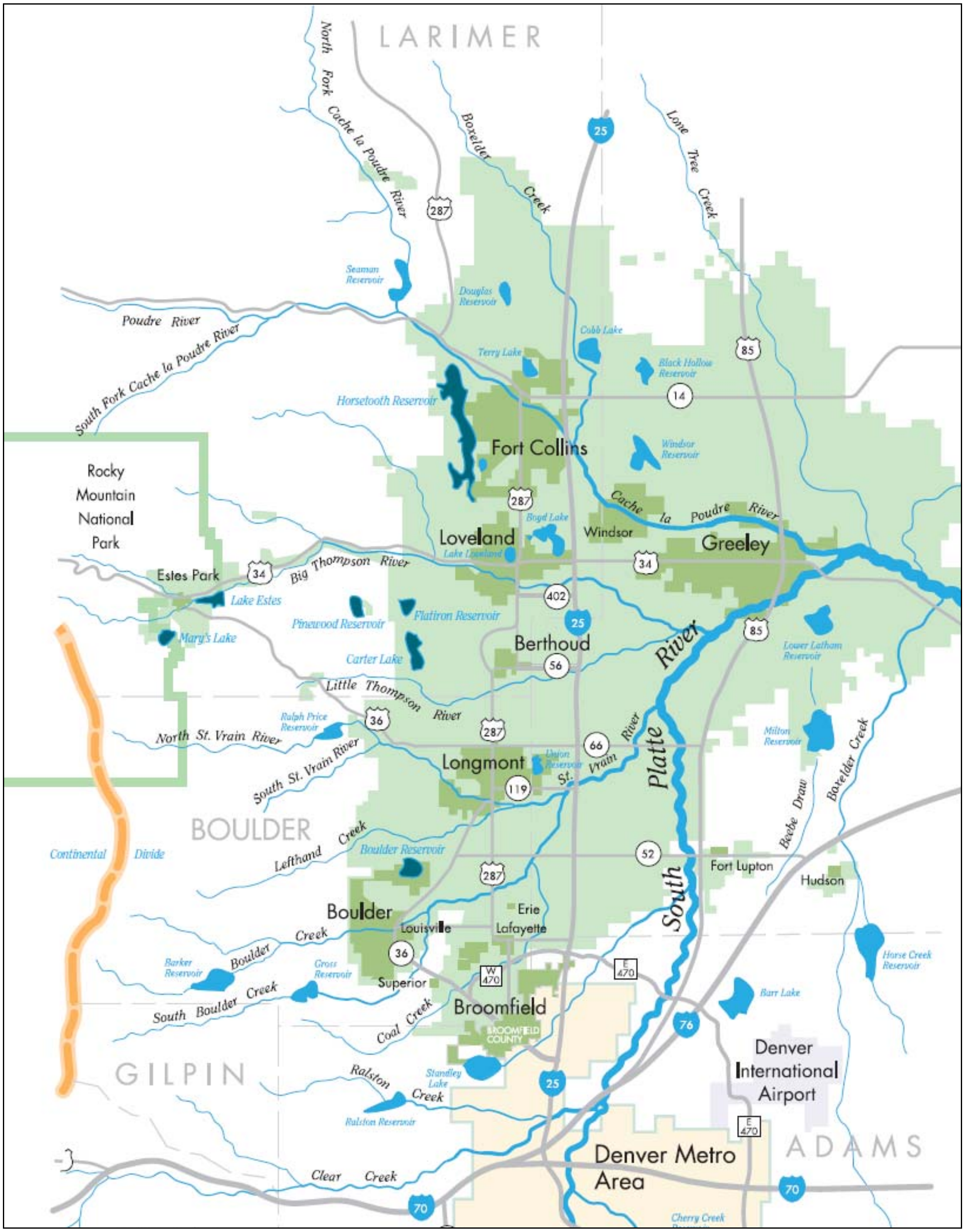

Figure 2. Northern Colorado Front Range River Basin Map

PROJECT FORMULATION

Water Availability

The South Platte River near Greeley, Colorado sits at the confluence with the Poudre River. The proposed SPWCP diversion location lies below the entire Colorado front-range population as well as below a substantial amount of irrigated agriculture. As such, the river flow is dominated by upstream treated municipal wastewater flows and agricultural groundwater return flows. Additionally, the river can receive high flows during the spring from both mountain snowmelt as well as rain runoff. The rain runoff in particular appears to be a growing component of the spring flows as development and corresponding urbanized impervious areas increase upstream.

Flows in excess of the existing ditch diversions are considered to be available for a new water rights appropriation. Most of the water rights on the South Platte River date back to the late 1800's and early 1900's. The SPWCP water rights by contrast have a conditional water right of 1992. Hence, for water to be available to the SPWCP, all other senior water rights which are in priority must be satisfied.

Figure 3 illustrates the monthly average available unappropriated water compared to the average flow in the river and the proposed pump station capacity for the SPWCP. From December through June, there is generally unappropriated water available to be diverted to storage. Note that these flows are based upon present operating conditions superimposed on historical hydrology for the years 1950-2005.

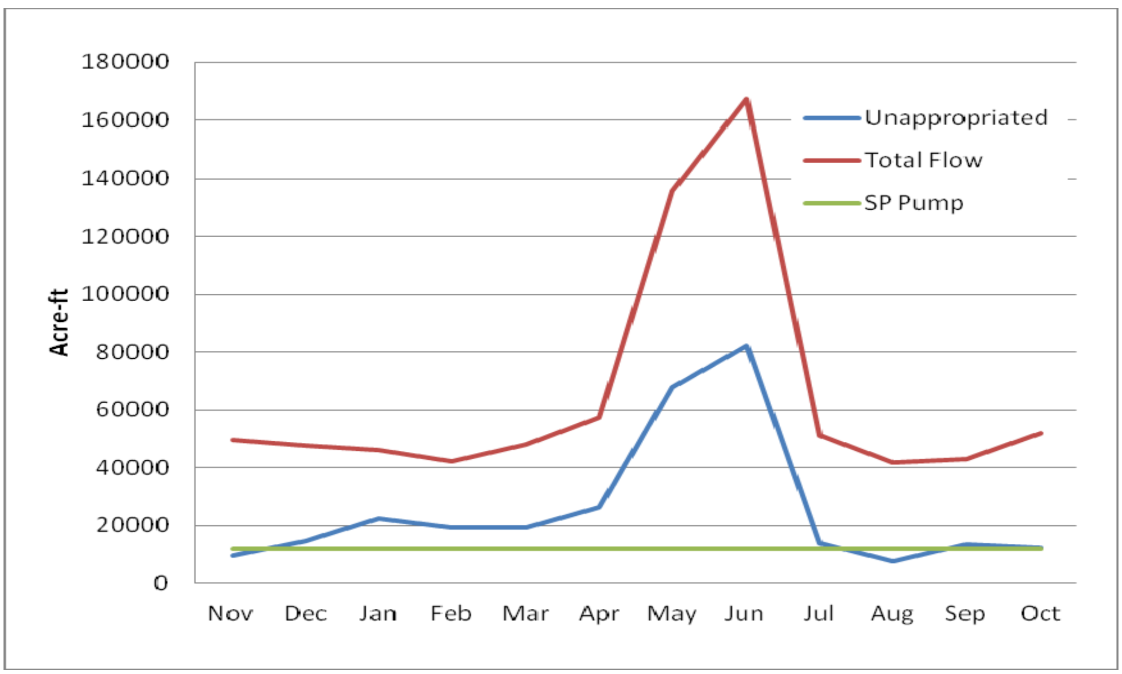

Figure 3. Average Monthly Water Availability

Presently, the South Platte River provides water directly to irrigators during the summer months. During these periods, very little if any flow is available under a junior water right. During the winter, there are numerous off-channel reservoirs and groundwater augmentation sites that fill if icing is not a factor. Once the reservoirs fill, or if ice begins to build in the fill-canals, the water rights "call" comes off, and flow becomes available for junior water rights. During the spring months when both mountain snow runoff is at its highest and when the front-range of Colorado receives the highest amount of precipitation, flows in the South Platte River can often exceed 5,000 to 10,000 cubic feet per second (cfs) and divertible flows are available during that period as well for a junior water right.

While demonstrating an approximation of average water availability, the above graph does not take into account the substantial differences which can exist from year to year on the South Platte River. Figure 4 shows the total water availability can range from zero in dry years to over a million acre-ft in wet years. Periods of drought such as 2000 through 2006 result in no available water for diversion by junior water rights, thus the need for longer term storage.

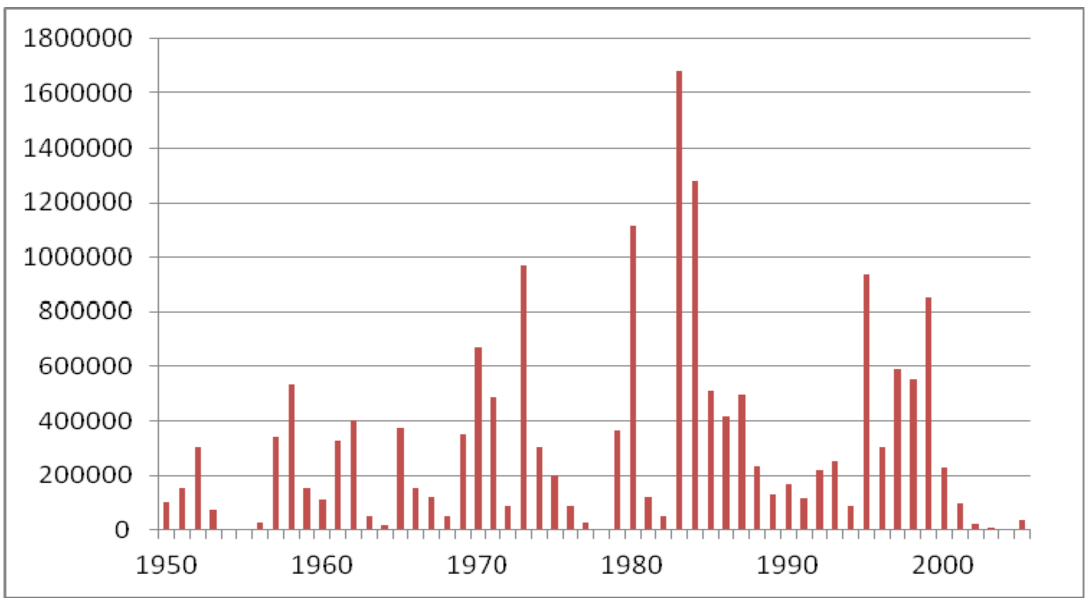

Figure 4. Annual Water Availability (acre-ft)

Project Configuration

The SPWCP involves pumping from the South Platte River to storage during times when water is available and releasing that water to two ditch companies – the Larimer and Weld and New Cache Ditch companies- during the irrigation season. The project would need to include a diversion off of the South Platte River, conveyance pipelines, and storage.

The current SPWCP project configuration utilizes surface storage at the proposed Galeton Reservoir. The project will include the following:

- South Platte River diversion
- South Platte River pumping station and forebay
- 29 miles of pipeline conveyance
- Galeton Reservoir

A map of the SPWCP facilities is shown on Figure 5.

Integration into NISP

Northern Water is moving the Northern Integrated Supply Project (NISP) forward on behalf of fifteen municipal water supply entities. NISP would develop 40,000 acre-ft of new yield utilizing both the Glade Reservoir Project and the SPWCP. A map of NISP is shown in Figure 6. The Glade Reservoir would be a new 170,000 acre-ft impoundment. It will receive supplies both from "flood flow" water rights off of the Poudre River as well as the exchanges from the SPWCP. Approximately half of the supply is from the flood rights and half from the SPWCP. The two components of NISP – Glade and the SPWCP – will work well together. Glade Reservoir will act as the primary storage vessel and allows the project to provide yield through extended drought periods. The SPWCP provides a relatively consistent year-to-year yield except for extreme droughts. The Glade Reservoir flood rights on-the-other-hand provides yield in approximately forty percent of years. Glade on its own has a storage-to-yield ratio of approximately ten. However, when combining with the SPWCP the overall storage-to-yield ratio of NISP drops by half to five, thereby making more efficient use of the Glade Reservoir.

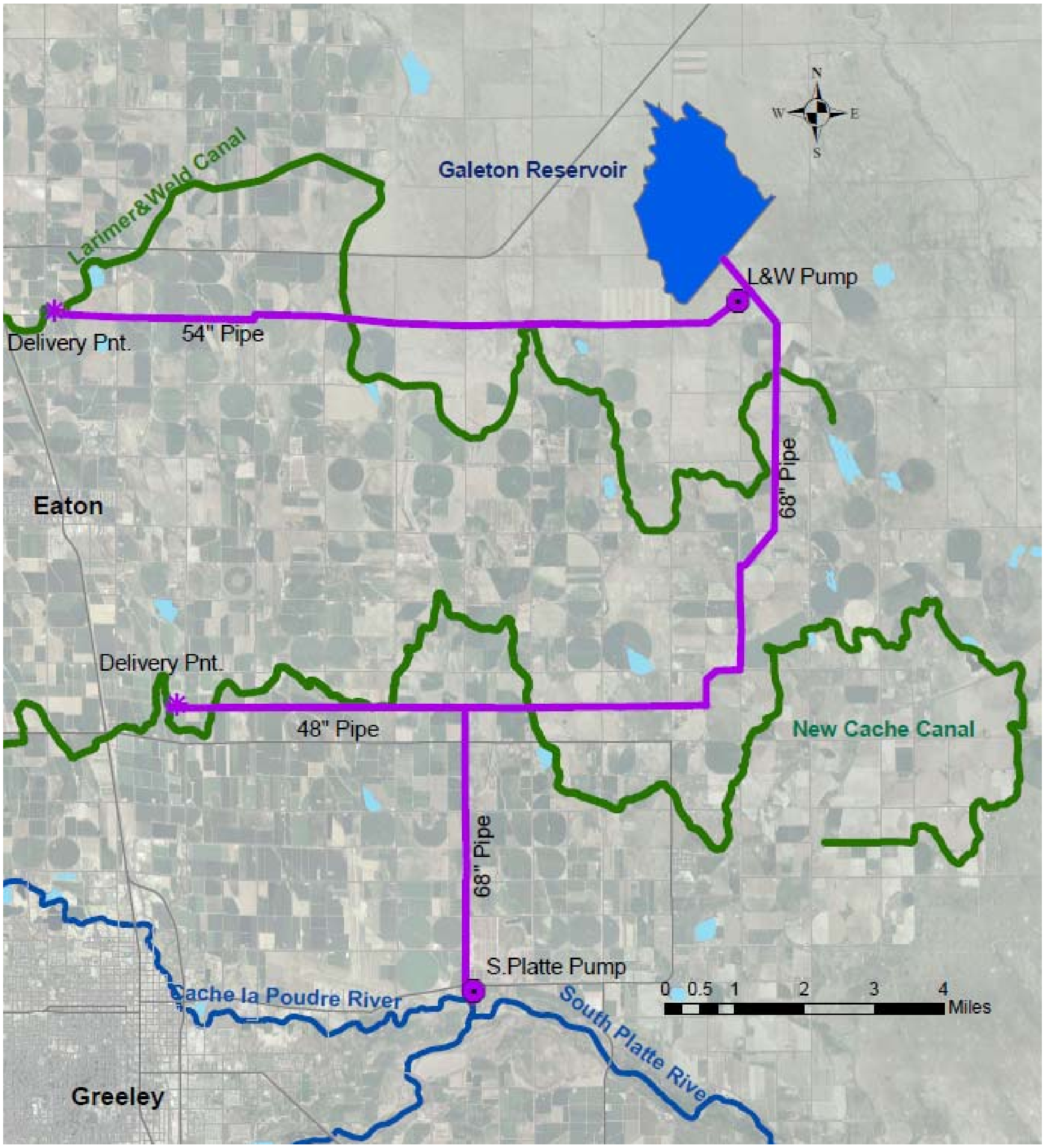

Figure 5. SPWCP Proposed Facilities

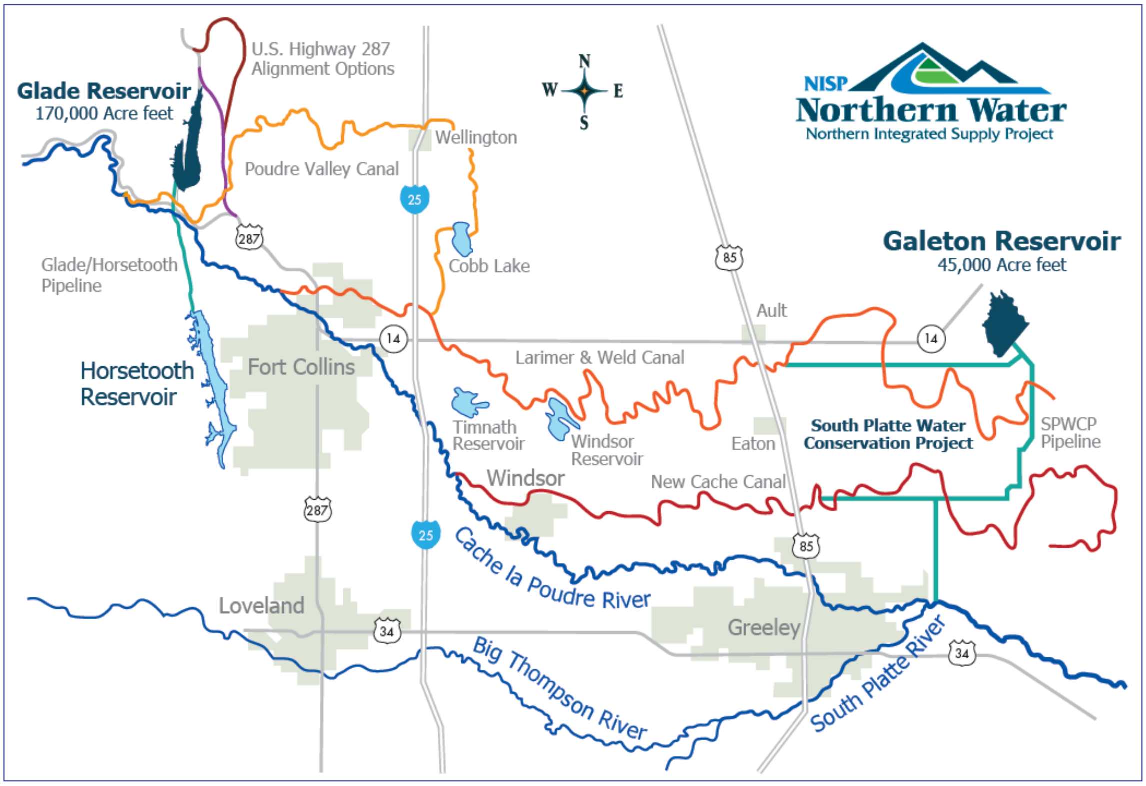

Figure 6. Map of NISP

NISP was formulated around the participant requested yield of 40,000 acre-ft. The Poudre and South Platte basins were modeled using MODSIM with a 50-year time period for both existing river conditions and potential future river conditions. The project facilities were sized to provide a firm yield through this period and achieve an average annual yield of roughly fifty percent from each of the project components. Table 1 provides the final SPWCP facility sizes which will be used for NISP.

Table 1. List of SPWCP Facilities, Capacities and Sizes

Facility	**Capacity**	**Description**
South Platte Diversion	200 cfs	Gated concrete diversion
South Platte Forebay	200 acre-ft	Lined gravel pit
South Platte Pump Station	200 cfs	13,500 hp - Vertical Turbine Pumps
South Platte to Galeton Pipeline	200 cfs	68-inch steel pipeline, 15 miles
Delivery Pipes	100 cfs	48-inch steel pipeline, 4 miles 51-inch steel pipeline, 10 miles
Larimer&Weld Pump Station	100 cfs	2,500 hp
Galeton Reservoir	45,600 acre-ft	Earth fill dam, 2 mile crest, 70 foot max height

NISP is presently nearing the end of the NEPA permitting stage. It is anticipated that the project design will start in 2014 with construction starting in 2016. The project will likely be built in phases with the final phase coming on line in the early 2020's. NISP will meet the majority of the participant future needs well into the 2040's to 2050's.

Project Operations

The SPWCP yield relies on the pumping of water from the South Platte River to Galeton Reservoir and the subsequent release of that water to the ditch companies. A conceptual diagram of the project operations are shown in Figure 7. The SPWCP will replace approximately 25,000 acre-ft of deliveries to the exchange area which represents approximately one-third of their irrigation supply.

Exchanges on the Poudre River will ultimately be administered by the Colorado State Engineer's office through the local river commissioner. The exchanges will be made to the Glade Reservoir headgate, or will be exchanged for Colorado-Big Thompson (C-BT) releases from Horsetooth Reservoir into the Poudre River for NISP participant use from other C-BT facilities.

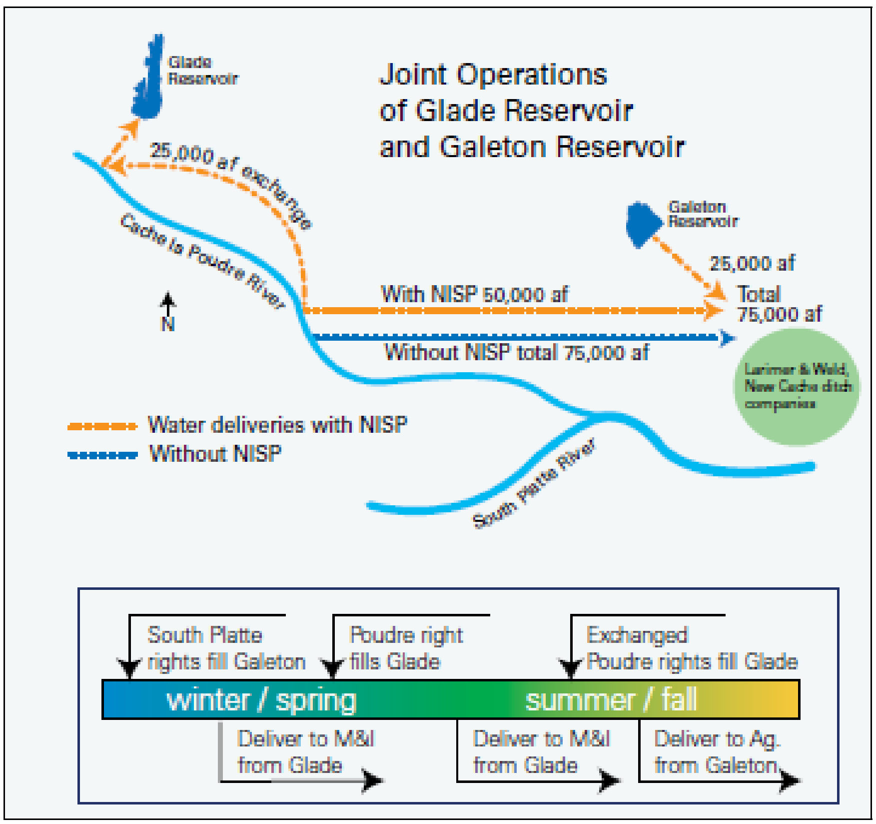

Figure 7. SPWCP Operation's Schematic

Project Costs

The SPWCP costs will include capital and operations and maintenance costs. Northern Water retained a team of Integra Engineering (now Dewberry) and GEI Consultants to prepare a feasibility design of the project facilities and in turn estimate the cost. The total capital cost for the SPWCP is estimated to be $171,000,000 and is summarized in Table 2 (2010 dollars). The total cost of NISP with Glade Reservoir is $490,000,000. The total cost per acre-ft of NISP yield is $12,300 for the capital costs.

Table 2. SPWCP Costs

Item	**Cost**
Diversion and Forebay	$5,200,000
South Platte Pump Station	$22,100,000
South Platte-Galeton Pipeline	$45,200,000
Delivery Pipelines	$19,300,000
Larimer and Weld Pump Station	$4,800,000
Galeton Reservoir	$46,100,000
Engineering/Administration $16,300,000	
Other Costs (ROW, Land, Other Facilities)	$12,000,000
Total	**$171,000,000**

Pumping will also be required for the SPWCP. The approximate lift from the South Platte River to Galeton Reservoir including headloss is 400 feet. Each acre-ft will require 500 kilowatt-hours of energy. Assuming an approximate cost of $0.06 per kilowatt-hour, the energy cost will be approximately $30 per acre-ft. With other maintenance costs, the total operations and maintenance cost is estimated to be $60 per acre-ft.

AGRICULTURAL WATER USER COORDINATION AND ISSUES

Ditch Company Background

The SPWCP relies on exchange of water supplies with the Larimer and Weld and the New Cache ditch companies. These companies date back to the late 1800's and together irrigate approximately 200 square miles utilizing approximately 120,000 acre-ft of water from the Poudre River. Primary crops include corn, alfalfa, sugar beets, brewing barley, pinto beans, and a small amount of vegetable crops such as onions and carrots. The local agricultural economy also includes large dairies and cattle feedlots which rely upon the forage crops for their operations.

Both companies utilize a combination of direct flow water rights, storage rights, and exchange rights for their supply. The typical exchange involves releasing water from storage to a senior water right, and then diverting all or a portion of the senior water right for their use. In the case of the Larimer and Weld system, their supply is diverted upstream of the City of Fort Collins and would be considered a high quality water. In the case of the New Cache system, their diversion takes place downstream of the discharge of treated wastewater from the Fort Collins area and has a quality that is therefore diminished.

Both companies use a similar structure for their governance and operations. Shares of the companies are held by irrigators which entitles them to a certain number of acre-ft each year, depending on projected water availability. Each company has a board of directors who oversee the management and decision making of the company. The staffing of the companies includes a manager, secretary, and ditch riders. There are also “sister” companies who own reservoirs as well as lateral companies who receive water from the main company.

Water Quality

The primary concern of both the individual irrigators and the ditch companies is that the South Platte River water might be of a lower quality compared to the high quality Poudre River water they are accustomed to using. In particular, this concern relates to salinity. The Poudre River is a mountain snow melt dominated river with a very high quality. The South Platte River on-the-other-hand has a greater percentage of waste water and ground water return flows and is lower in quality.

Salinity is the total concentration of dissolved ions in a system. Typically, ions contributing to salinity include the cations Na (sodium), K (potassium), Ca (calcium), Mg (magnesium), and the anions SO4 (sulfate) and Cl (chlorine), HCO3 (carbonate). While different ions can cause different effects on plant growth, plants respond mainly to the sum total of ion concentration. If there is an excess of sodium, however, or high pH, water quality can degrade to the point of being unusable. In soils with high clay contents, high sodium in applied water can cause soil surface dispersion and sealing, effectively destroying any soil structure. This can lead to drainage problems, infiltration problems, and reduced porosity of soils.

The primary measurement of these ions is determined by electrical conductivity (EC) as measured in deciSiemens per meter (dS/m). Typical EC measurements in the Larimer and Weld Canal are approximately 0.5 dS/m. New Cache Ditch company measurements are higher at approximately 0.8 dS/m on average. The South Platte on the other hand is dominated by ground water return flows and can range from as little as 0.3 dS/m when spring snowmelt and rainfall dilution flows are high to 1.5 dS/m when flows are low. There is, therefore, the potential that salinity could increase in the canal systems as a result of the introduction of SPWCP water.

To address the salinity concern, Northern Water retained Dr. Glenn Hoffman to study the particular area that is being considered and make recommendations relating to the operation of the SPWCP. In addition to the potential salinity of the applied water, Dr. Hoffman considered the soils types, irrigation methods, and rainfall contribution. The conclusion was that there would be virtually no reduction in crop yields with the introduction of South Platte water. Only dry-beans have the potential of any decrease in yield and this would be on the order of approximately five to ten percent. Dr. Hoffman recommended a blending operations plan which would alleviate potential issues. The blending could be adjusted to meet the specific water quality of stored Galeton Reservoir water. The likely blending is approximately one third SPWCP water to two thirds native ditch water.

Northern Water continues to obtain salinity data via its remote sensing network. This program will continue through the actual implementation of the project to insure that there is no yield reduction impact to the irrigators. Additionally, specific water quality samples are taken to measure the specific ion constituents in the water. These analyses have shown the South Platte ion content to be dominated by calcium and sulfates and less so by sodium and chlorides.

Specifically, under certain conditions, sodium can cause soil problems and corresponding plant growth issues. Calcium can help alleviate this issue. The measurement of the problem is the Sodium Adsorption Ratio (SAR). It is the ratio of sodium ions to calcium and magnesium ions. A ratio greater than 10 is considered potentially harmful to irrigated crops. Measurements taken of South Platte water during a range of flows show the SAR to be between 1 and 2. Therefore, the SAR is not considered to be problematic for this project.

Ditch Company Compensation

Northern Water will need to receive the permission of the ditch companies to tie into their systems and exchange their water. Northern Water and the companies are working cooperatively on formulating contracts which describe how the project will integrate with their operations, and what compensation they will receive. Discussions with the companies have thus far indicated an interest in additional water as opposed to monetary compensation. Specifically, the following measures are being discussed:

- Provide an additional ten percent of water for each acre-ft exchanged
- Pump additional water when the South Platte Pump Station has flow available and Galeton Reservoir is full
- Give a preferred right to Colorado Big-Thompson unit rental from NISP participants in years that they have excess available
- Provide delivery infrastructure to allow for better utilization of their existing reservoirs

Operational Coordination with the Ditch Companies

Northern Water will coordinate the operations directly with the ditch companies. The goals are two-fold: 1) achieve the desired blending level between Galeton water and ditch water and ensure that the water levels in the ditch upstream of the SPWCP delivery point are high enough to make deliveries to those share holders. As previously discussed, water from Galeton Reservoir will be delivered at a rate up to 100 cfs to each ditch. The company's diversion from the river will then be curtailed a like amount. Northern Water is presently preparing a ditch company inventory of head gates, check structures, and other ditch features. This information will be integrated into a HEC-RAS hydraulic model to verify water levels in the canal are sufficient to make deliveries to upstream head gates. If the model finds that there are times when levels are insufficient to make deliveries, either the exchange will be curtailed, or additional check structures will be installed.

Northern Water will also work with the ditch companies to coordinate their SCADA systems with Galeton releases. The companies presently have some check structure automation. It is anticipated that with the ability to make instantaneous deliveries from Galeton to locations much further down the ditch, check structure and diversion structure operations will be automated via SCADA allowing less wait time on river diversion changes to the system.

Potential Risk

The primary risk to the SPWCP arises from the potential sale of the company shares to outside municipal water providers through the practice of buy-and-dry. The project exchange is formulated upon the assumption that the farmers will continue to irrigate in the area. In the event that the water is removed out of the system, there becomes a risk that project operations could be impacted. The following are methods that can be employed in the long term to address these risks:

- Monitor the amount and location of agricultural to municipal conversion. The amount of water which NISP will exchange through the SPWCP represents approximately a third of the water applied in the particular exchange area. Some amount could be sold out of the area and the project would remain operational.
- Extend the pipelines to the west. The project presently assumes an exchange area in the eastern portions of the ditch companies. The delivery pipelines could be extended to the west at a minor cost relative to the entire project and thus lessen the chance that the exchange would be impacted by transfers.
- Enter into "water easement" arrangements with irrigators. In this case, irrigators would be compensated for their right to sell their water to outside users. The value of the "easement" would presumably be the difference between the municipal value and the irrigation value of the water. The water with this easement could be sold to other irrigators as long as the water was used within the exchange area.
- Purchase the company shares and lease back. Under this arrangement, if shares become available for sale, NISP would buy shares and then lease them back to irrigators within the area.
- Work with dairy and cattle feedlot operators to incentivize keeping water in the exchange area. There are a number of very large dairy and cattle feedlot operators in or near the exchange area. These operations typically do not own a large portion of the land which is used to grow the forage and feed crops, typically corn and alfalfa. Instead, they contract with local growers for their crops. These operations have a mutual interest with NISP in maintaining the continuation of irrigation for raising forage crops. There may be ways of cooperatively working with cattle operations and growers to achieve the goal of continued irrigated agriculture in the exchange area.

It is likely that a combination of the above approaches will be used to insure that the SPWCP exchange continues. The approach can be implemented over time so that financially it becomes part of the operations and maintenance budget and not the capital construction budget. Long term it will insure that at least a portion of the exchange area remains agriculturally productive.

CONCLUSIONS

The SPWCP will provide a new water supply to municipal suppliers through a cooperative program with the Larimer and Weld and New Cache ditch companies within the Poudre River basin. Through NISP, municipalities will be able to take advantage of the high quality water that the companies presently divert while providing a water supply suitable for irrigation to the ditch companies for agricultural use. Northern Water on behalf of the fifteen NISP participants has been working with the ditch companies to address their concerns and to find an equitable approach to provide net benefits to the company shareholders.

Ultimately, the SPWCP will rely on a partnership with the ditch companies. It will help insure the long term viability of agricultural production in the region while assisting in satisfying some of the anticipated additional regional municipal water supply needs.

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WATER RESOURCES PLANNING TO WATER TRANSFERS TO MODERNIZATION OF AN IRRIGATION DISTRICT: OAKDALE IRRIGATION DISTRICT CASE STUDY

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ABSTRACT

Oakdale Irrigation District (OID) was formed in 1909 and provides pre-1914 water rights to over 55,000 acres of irrigated farmland located within the northern San Joaquin Valley of California. The district's situation is similar to many irrigation districts in the Central Valley; it has an aged and often failing infrastructure which has had little investment over the years; it has an intermixed customer base of both urbanizing ranchette lands, expanding dairies and a rapid conversion to high value permanent crops; it has a demand for more flexible water deliveries and services from its customers; and has limited financial resources to meet those demands.

With that backdrop, initiated in November 2004 and completed in June 2007, OID developed a Water Resources Plan (WRP) as a strategic roadmap for addressing those issues. Today the district is moving forward with the implementation of a $170 million capital improvement program to meet the multifaceted needs of the district. Those needs as outlined in the WRP include the protection of the District's water rights; an increase in agricultural water supply reliability during droughts; protection for the local areas surface and groundwater supplies; along with a roadmap to modernize and rebuild a century old system to meet the needs of its changing customer base. Regional water transfers are being used as the basic funding mechanism to make it all happen.

The paper will provide a background of the drivers that got the OID to begin the planning process; it will discuss how the planning process evolved; what the findings and recommendations were in the final Water Resources Plan (WRP); and finally, how those recommendations are being moved forward to implementation.

BACKGROUND

History of OID

In 1909 OID was organized under the California Irrigation District Act by a majority of landowners within the district in order to legally acquire and construct irrigation facilities and distribute irrigation water from the Stanislaus River (ref. Figure 1). 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. Both districts continued to expand their operations over the ensuing decades.

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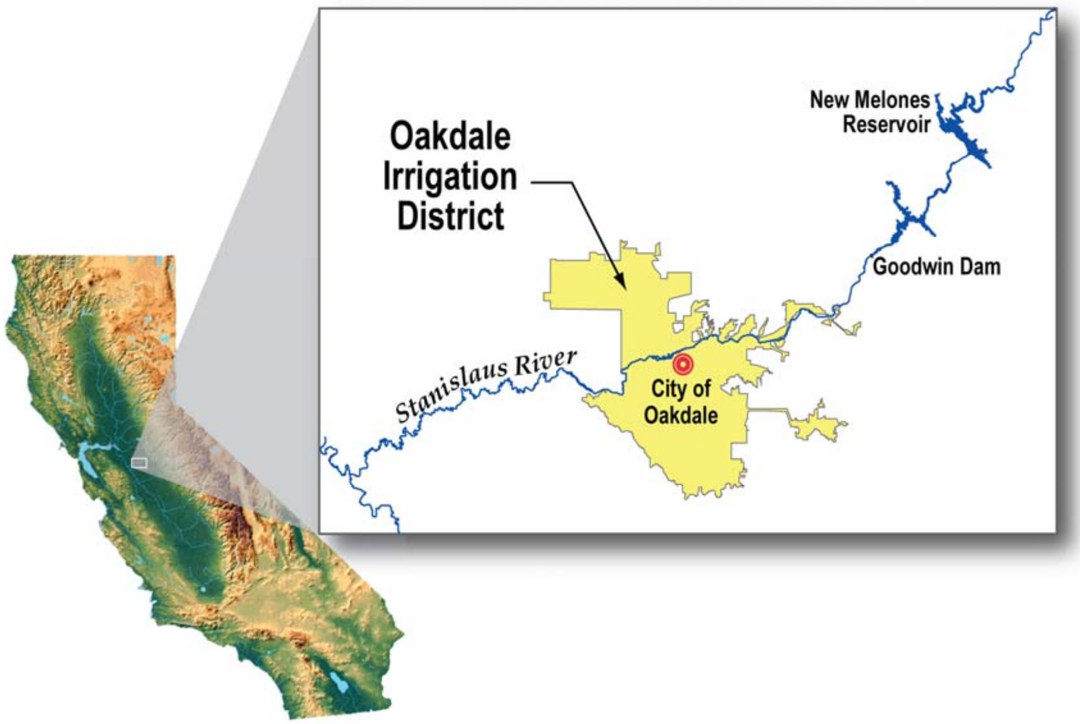

Figure 1. Location of Oakdale Irrigation District

Since their creation, OID and SSJID have constructed dams and reservoirs to regulate surface water storage and deliveries. Most dams were constructed in the 1910s and 1920s, including Goodwin Dam (1913), Rodden Dam (1915), and Melones Dam (1926), which provided 112,500 acre-feet (ac-ft) of shared capacity. To provide supplemental water storage for OID and the SSJID, the Tri-Dam Project was created in the 1940s. Sites were approved in 1948 for Donnells Dam and Beardsley Dam on the Middle Fork of the Stanislaus River, and for Tulloch Dam above Goodwin. The two districts entered a joint agreement to carry out the proposed project and now jointly own and operate the three storage reservoirs for a combined storage capacity of 230,400 ac-ft.

In the early 1970s Reclamation replaced the Melones Dam with the larger New Melones Dam and Reservoir. The districts have an operations agreement with Reclamation to utilize the federally owned New Melones Reservoir.

Significant capital investment has led to a stable, plentiful water supply for the district. Over the last 50 years, the district has focused its financial resources principally on paying off these capital investments; as a result, the district has invested little in replacement, modernization, automation or rehabilitation of its existing system over the years.

Internal and External Drivers Necessitated a Change

Internal Issues: The position of the district in 2003 was not enviable. While water resources were plentiful to meet crop water needs for customers, the operational control of that water was lacking. Principally due to a lack of modern, and often failing, infrastructure that inhibited the district's ability to manage the system efficiently. System failures began dominating the annual workload and budget as years of non-investment in the delivery system began to show.

On-farm water use was equally deficient in terms of efficiency. Without a good system of controls in the canals of the district, farmers experienced significant canal fluctuations which impaired their ability to efficiently manage water on their side of the farm gate. Couple the above with foothill farming practices that had for years utilized wild flooding as its principle form of irrigation, and on-farm water use efficiency was not very high.

The district was also experiencing a change in its landscape and in the customer base it served. Pasture, which dominated the area's agriculture for years, was being converted to high value tree crops like almonds and walnuts. These changes were met with demands by farmers for a different service standard for their water deliveries. Similarly, a significant amount of pasture was being converted to feed crops such as corn and oats as dairies began buying and converting pasture for their expanding operations and to meet new regulations regarding nitrogen management within their operations.

External Issues: Water quantity issues in California have always been a subject of concern but in recent years, these shortages and their repetitiveness seemed to be on the increase. While the district has three (3) water transfers to its neighbors, one 15,000 acre foot transfer to the City of Stockton via the Stockton East Water District and two (2) transfers totaling 26,000 acre feet to the Bureau of Reclamation for environmental and water quality purposes, there was pressure to do more by the City of Stockton as the transfer term of the original contract was reaching its end. Similarly, the City and County of San Francisco has always expressed an interest in discussing the future status of OID's water supply.

The recent loss of the agricultural waiver for the discharge of surface water placed another problem both on the district and its agricultural customers. Farmers were looking towards the district to help with these changing regulations and the district, not being in a financial position to due otherwise, looked at these problems as on-farm issue, not one the district should be involved in.

Needless to say, the complexity of water issues, both locally and at the state level, necessitated a rethinking of OID's current practices and priorities in order to guarantee full protection of the district's and region's water supplies into the future. The District's Board of Directors and management, recognizing this challenge, commissioned CH2M HILL in the fall of 2004 to explore the issues facing OID and develop a comprehensive plan to respond to these issues. These were the principal objectives of the Water Resources Plan (WRP).

THE WATER RESOURCES PLAN

In the development of the WRP, the OID Board of Directors developed the following five goals that they agreed key to developing water management strategies and alternatives:

- Provide long-term protection to OID's water rights
- Address federal, state, and local challenges
- Rebuild and modernize an out-of-date system to meet changing customer needs
- Develop affordable ways to finance improvements
- Involve the public in the planning process

The WRP evaluated the district's water resources, delivery system, and operations, and examined land use trends to determine how future changes in these areas will impact water supply and demand during the next two decades. The plan also provided specific, prioritized recommendations for OID facility improvements that would comply with the California Environmental Quality Act (CEQA) and accommodate available financial resources.

A recap of the WRP findings and recommendations are provided in the following paragraphs.

General Background of OID

OID is located in the northeast portion of the San Joaquin Valley, about 30 miles southeast of Stockton and 12 miles northeast of Modesto. The OID service area consists of 72,500 acres between the Sierra Nevada and the Central Valley along the San Joaquin–Stanislaus County line, surrounding the city of Oakdale and bordering the cities of Riverbank and Modesto. The district's sphere of influence (SOI), land that the district is permitted by law to annex but to which it has not yet provided service, extends 86,290 acres farther to the north and east into Calaveras County. The Stanislaus River flows from the east through the center of the district service area and SOI.

Situated near the base of the Sierra Nevada foothills, OID's topography varies from gently rolling hills to the east and south of Oakdale to nearly flat around Riverbank. Approximately 75 percent of the land within the OID service area consists of irrigated agriculture. Native vegetation and rangeland dominates the land immediately outside the OID service area to the north, south, and east.

OID experiences mild, moderately wet winters and warm, dry summers typical of the Central Valley. Average temperatures range from the mid-forties in winter to the mid-nineties in summer. Precipitation averages about 12 inches annually, over 85 percent of which occurs between November and March. Average evapotranspiration (ET) is approximately 46 inches seasonally (April through October). Climate conditions are generally uniform throughout the district.

The District Today

Currently, the district maintains over 330 miles of laterals, pipelines, and tunnels, 29 production wells, and 43 reclamation pumps to serve local customers. In general, the district's facilities, system operations, political organization, and administration have not changed significantly over the last several decades. Nearly all water supply canals were constructed more than 90 years ago. In recent years, however, the district's customers, land use, and financial resources have developed in a direction that may influence the way OID provides services and conducts business in the future. The following sidebar highlights important background facts about the district.

OAKDALE IRRIGATION DISTRICT FACTS

Year OID was organized: 1909

Cost to OID and SSJID for existing irrigation system and water rights in 1910: $650,000

Total district acreage: 72,500

Total irrigated acres: 55,600

Annual diversion right: 300,000 acre feet

Diversion point: Goodwin Dam

Maximum diversion rate from Goodwin Dam: 910 cfs

Total distance of water delivery system: 330 miles of canals (open, lined, and buried pipelines)

Number of agricultural wells: 24

Number of agricultural and domestic water accounts: 3,500

Percent of OID agricultural customers who farm parcels of 10 acres or less: 60 percent, constituting 12 percent of OID land

Percent of OID agricultural customers who farm parcels of 40 acres or more: 4 percent, constituting 60 percent of OID land

Analyses and Findings

Analyses conducted for the WRP included detailed land use modeling, water balance modeling, on-farm surveys, a comprehensive infrastructure assessment, and the development of a phased infrastructure plan to rehabilitate and modernize an out-of-date system. The integrated approach also included water right evaluations, groundwater studies, development and evaluation of program alternatives, financial analyses, environmental compliance, and public outreach. The following discussion summarizes some of the key areas of evaluation that were conducted in the study.

Land Use

OID currently serves 2,800 agricultural customers on approximately 55,600 acres of serviceable land. The district also provides water to 700 domestic accounts primarily east of the City of Oakdale. Agriculture dominates the lands in and surrounding OID, as shown in Figure 2. Within the district service area, pasture makes up approximately half of the total land use, or about 32,000 acres. The other half of the district consists of orchards, corn and oat crops, and municipal land in relatively even proportions. Only a small percentage of the land in the district's service area consists of native vegetation. Outside the OID service area but inside the district's SOI, native vegetation dominates three-quarters of the land, or approximately 47,000 acres, as shown in Figure 3. Orchards and pasture crops make up 11 percent and 9 percent, respectively. Corn and oats make up 6 percent. Rice and urban/industrial areas make up 1 percent or less of the district SOI outside the service area.

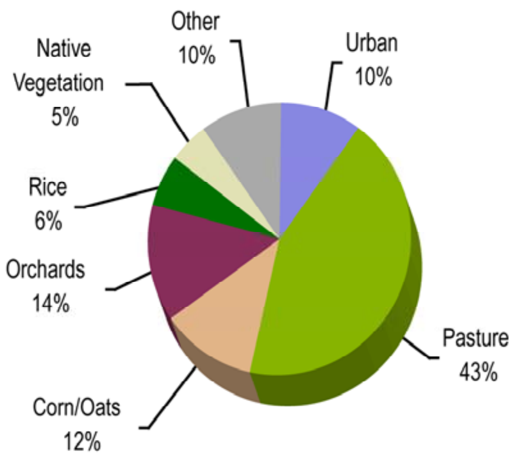

Figure 2. Land Use Distribution in OID

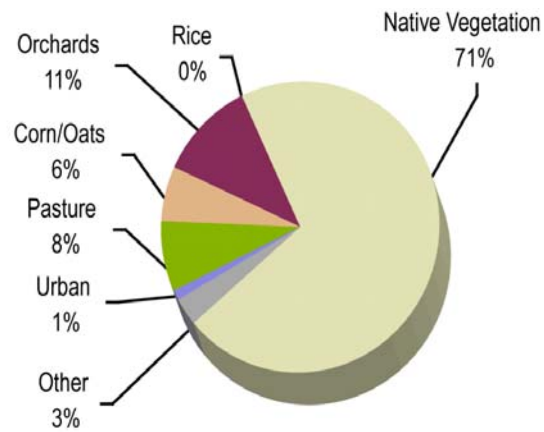

Figure 3. Land Use Distribution within OID Sphere of Influence

Land use within the OID service area has shifted in recent years, and these trends point to continued change in the future. Some agricultural land around the cities is urbanizing. The City of Oakdale is experiencing steady population growth. It is forecasted that over the next 20 years, 6,000 acres of agriculture in OID will be replaced by municipal land, resulting in fewer irrigated acres and a lower demand for OID water.

Many OID customers are also changing the types of crops they are growing. Across the region, higher-value tree crops are replacing pasture. Orchards use less water and require a more intensive, responsive level of irrigation service than is currently provided by the district. Land ownership is also changing as large parcels are subdivided, leading to increased ranchette-type development in some areas. All these factors may necessitate changes to the level of services the district can currently provide.

Of particular note is that orchard acreage outside OID's existing service boundaries has more than doubled in the past decade. This is the result of accelerated market conditions for nut crops. The irrigation water source for orchards outside OID is almost exclusively groundwater. The majority of orchard development has occurred immediately adjacent to OID's eastern boundary. This development offers significant opportunity for expansion of service by OID.

Forecasted Trends As shown in Figures 4 and 5, forecasted land use inside and adjacent to the current OID service area is expected to continue changing substantially. While pasture is generally projected to decrease within OID, orchards are expected to increase nearly 50 percent to approximately 15,000 acres in 2025. Nearly all these orchards are expected to implement fairly efficient irrigation systems (such as micro sprinklers), resulting in significant water savings. It is expected that most orchards (average applied water approximately 3 ac-ft per acre) will be planted on ground that was previously pasture (average applied water approximately 6 ac-ft per acre). This will result in the applied water demand being essentially cut in half. Also, the efficiency of the irrigation systems will result in other water savings, including reduced—and in many cases eliminated—tailwater production.

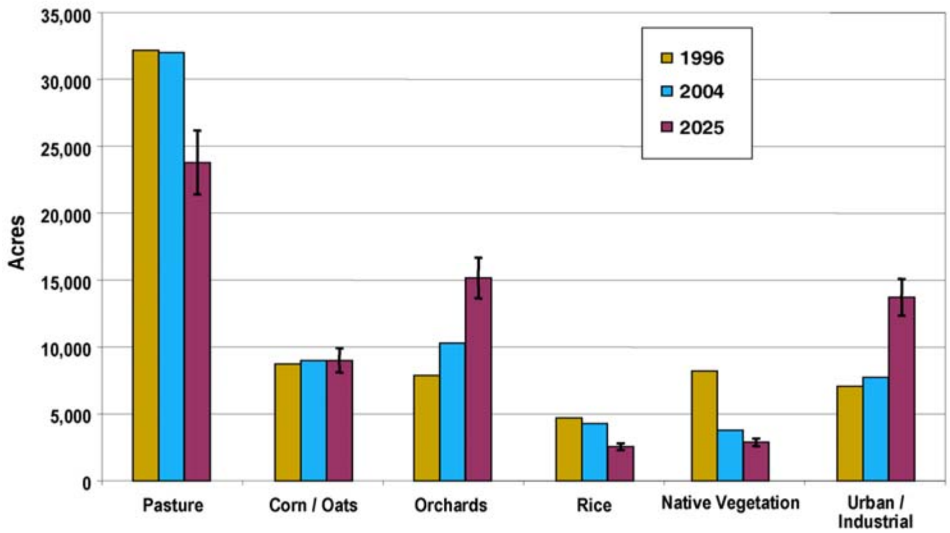

Figure 4. Historical and Forecasted Trends Inside OID Service Area

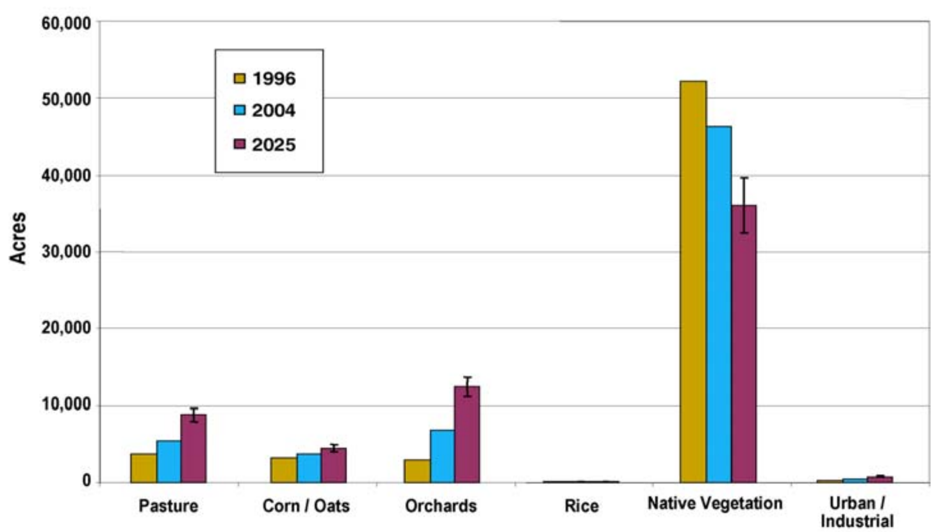

Figure 5. Historical and Forecasted Trends Outside OID Service Area

The forecasted 2015 City of Oakdale population is 29,000. Actual holding capacity of the 2015 boundary area, if completely built out, would be about 39,000. New residential growth through 2015 is forecasted to occur in all directions around the city, and will likely fill in four primary areas within the 2015 growth boundary. Accounting for additional urbanization between 2015 and 2025, 10 percent of total current OID lands, most of which is currently irrigated agriculture, will likely be lost to urbanization by 2025.

Land Use Conclusions Historical land use and forecasted changes will significantly influence the future of OID and service to its customers. Forecasted land use is a fundamental element of the WRP and has significant influence over the suggested recommendations for the future.

Infrastructure Assessment

As part of the WRP, a detailed infrastructure assessment was conducted. Those findings concluded that major vulnerabilities existed within the OID's primary water delivery system off the Stanislaus River and that a large proportion of the system had significantly deteriorated. Additionally, changing customer needs and service conditions necessitated that OID modernize its system to provide more responsive and reliable service. The assessment performed included the following areas of OID's water delivery system:

- Joint Main Canal, North Main Canal, and South Main Canal
- Regulating reservoirs
- Primary distribution system
- Groundwater wells
- Drainwater and reclamation facilities
- Supervisory Control and Data Acquisition System (SCADA)
- OID's standards for providing irrigation service to its customers

Water Balance Modeling

To facilitate this analysis, a systemwide operational water balance model (WBM) was developed. The WBM provided a flexible analytic tool for simulating a range of long-term operating scenarios and overall WRP alternatives.

The primary water balance unit of analysis was the Lateral Service Area (LSA). Each LSA represented the portion of the OID service area supplied by a specific distribution lateral. Water supply into the LSA is provided by a combination of surface water, groundwater from wells, and reclamation pumps (drainwater). Water leaves the LSA through ET, deep percolation, tailwater spills to drains, and operational spills to drains. The drainage basin is the object in the WBM for tracking the supply, reuse, and outflow of drainwater. Each LSA overlaps one or more drainage basins, into which its tailwater and operational spills flow.

A baseline operations water balance was created to simulate the primary water components of OID's overall system under existing land use and varying hydrologic and climatic conditions. The baseline model was developed using 2004 land use information (which represents the most recent land use survey data available), irrigation efficiencies developed from an on-farm survey at OID, available outflow data from OID's boundary outflow program, and average- and drought-period climatic (ET and precipitation) records. Land use was developed using geographic information system coverage for OID's assessed parcels combined with California Department of Water Resources land use survey data. By starting with a baseline model that reasonably represents existing conditions, the model can then be used to evaluate the net impacts of key factors influencing OID's long-term water demand and supply through the 2025 planning period, such as crop shifting and changes in farm efficiency levels, annexation of new service areas, varying levels of drainwater reclamation, groundwater pumping, and distribution system improvements.

Alternative Development and Evaluation

The WRP evaluated the district's water resources, delivery system, and operations. It surveyed on-farm water use and practices and evaluated the infrastructure and modernization needs of the OID. In conjunction with this comprehensive assessment, the WRP examined land use trends to project how future land uses will impact water supply and demand over the next two decades. Lastly, the water balance efforts provided insight on projected water use and various means by which the OID may put to beneficial use water that would be generated through implementation of the WRP.

To address the expected changes in future OID customers' needs and to reasonably and beneficially use the district's water supplies, four distinct programmatic alternatives were developed and evaluated. These alternatives encompassed a range of reasonable options available to the district in response to the land use, regulatory, resources, and customer-driven issues presented in the WRP. The term *programmatic* is used to emphasize that the alternatives evaluated in the WRP are broad-based and strategic, and represent policy-level options for OID's consideration.

Evaluation Methodology Applying some key common assumptions to all alternatives, a detailed methodology was employed to determine key water balance components for projected 2025 conditions for each programmatic alternative. Next, decisions regarding the provision of service to customers outside OID but inside the SOI (annexation) and water transfers were made for each alternative. Lastly, a Financial Model was used to analyze various strategies for viably supporting each alternative.

The four alternatives, combined with the viable financial strategies for implementation, results in a set of 13 distinct options, all of which are financially and technically feasible. Following the evaluation, a matrix summarizing each alternative was then compared to the WRP goals. From this comparison emerged the Best Apparent Alternative. The results of the water balance analysis for each programmatic alternative are summarized in Table 1.

In multiple programmatic alternatives, an initial and final level of firm and variable water transfers are identified. A firm water transfer is defined as the quantity of water provided in every year, including droughts. Variable transfers are reduced during dry years as Stanislaus River supplies to OID are curtailed. OID currently transfers water to a neighboring special district and to the federal Bureau of Reclamation. These existing transfers total 41,000 ac-ft. Of that volume, 30,000 ac-ft are firm and 11,000 ac-ft are variable. Over the course of WRP implementation, the quantities of firm and variable supplies available for transfer were forecast to increase to 50,000 ac-ft and 17,000 ac-ft, respectively. In Alternative 2, these supplies are assumed to be transferred. Alternative 4 assumes that these supplies support expansion of service into the SOI. Alternative 3 assumes that the firm quantity is transferred, and the variable quantity supports expansion of service into the SOI.

Table 1. Summary of Programmatic Alternatives and Associated need to change the format of the table for ease of reading

Alternative	Description	Key Components
1	Continue Present Practices	The "do nothing" alternative Limited investing in service improvements Continues same level of replacement and rehabilitation No annexations Continue minimum transfers of 30,000 ac-ft up to a maximum of 41,000 ac-ft.
2	Maximize Service Improvements within District Boundaries	Improve service standards Rehabilitate and modernize system Provide drought protection measures with added deep wells and reclamation facilities No annexations Finance all costs through transfer of 50,000 ac-ft and additional variable transfers of 17,000 ac-ft.
3	Maximize Service Improvements within District Boundaries and Moderate Expansion of Service within OID's SOI	All elements of Alternative 2 except allows annexation of 4,250 acres of expanded service in SOI to utilize 17,000 ac-ft Finance all costs through transfer of 50,000 ac-ft
4	Maximize Expansion of Service within OID's SOI	Annexation of 16,750 acres of expanded service in SOI to utilize 67,000 ac-ft of available supplies Annexations would consume available water allowing for no water transfers

Evaluation Results The Financial Model analyzed various strategies for viably supporting each programmatic alternative. This analysis led to the selection of Alternative 3 as the Best Apparent Alternative. This alternative maximized improvements in the district, provided for moderate expansion into the SOI, most strongly supported all the WRP's goals, and kept water rates at a favorable level. Following Board endorsement, Alternative 3 was termed the Proposed Program.

THE PROPOSED PROGRAM

To comply with the California Environmental Quality Act (CEQA), OID prepared a Programmatic Environmental Impact Report (PEIR) to address the potential environmental impacts resulting from the implementation of the Proposed Program. That document was concluded and certified in June 2007.

The resultant Proposed Program adopted by the OID for implementation is currently in the Implementation Phase. The major components of the adopted Proposed Program consist of the following projects and programs:

- Flow control and measurement projects
- Canal Reshaping and Rehabilitation Program
- Groundwater Well Program
- Main Canal and Tunnel Improvement Program
- Pipeline Replacement Program
- Regulating Reservoir and Woodward Reservoir Intertie
- Turnout Replacement Program
- Drainwater Reclamation Program
- Surface water outflow management projects (Reclamation Program)
- Water transfers
- Expansion into the SOI

In all, the Program components in the WRP total $169 million in modernization, rehabilitation and replacement projects to be implemented over the next 20 year period. The principle method of funding this cost will be from revenues generated through water transfers.

FINANCING THE IMPLEMENTATION OF THE WRP

The financial support for the implementation of the WRP programs will come from water transfers. Currently the OID has 41,000 acre feet in existing transfers and will produce another 10,000 acre feet of transferable water with full implementation of the WRP over the next 20 years. With projected implementation costs for the WRP at $169 million, and assuming 20 year financing, and 50,000 acre feet of transferred water, the return cost on transferred water is $200 to $250 per acre foot depending on finance terms.

Placing this on an annual basis, OID would need an average revenue stream of $12.5 million per year for its 50,000 acre feet of transferred water to fund the rebuilding, and modernization of OID without unreasonable and preferably no water rate increases to its customers. To meet that need, the following range of transfer terms would make that possible;

- OID could find a buyer of 50,000 acre feet at $250 per acre foot,
- OID could find a buyer of 25,000 acre feet at $500 per acre foot,
- OID could find a buyer of 12,500 acre feet at $1,000 per acre foot,

Water Markets

There are three water markets available to the OID in which to evaluate transfer opportunities. Each market has a different ability to pay and comes with a different set of politics.

High End Metropolitan Areas. These market areas come with a capacity to pay but the local politics of completing such transactions can be difficult for small rural irrigation districts. Water kept locally serving local needs is a mantra of concern and is not without some merit. However, the benefit in marketing in these areas is the ability to receive high returns with less water in transfer thereby, in the long run, meeting both the financial needs of the irrigation district and the needs of the local community in keeping as much water locally as is financially possible.

Local and Regional Areas. These markets are only now being exposed to the true value of water. For many years, the local and regional areas have relied on a seemingly abundant groundwater supply that is now become less than usable in the San Joaquin Valley. With the implementation of the new arsenic rule, nitrate contamination issues, salt water intrusion from years of overdraft, etc. cities in the local and regional markets are only now beginning to face avoided cost issues for their future water supplies.

Agriculture Markets. This market's capacity to pay is simple to define. Their avoided cost for water is equivalent to that which they would pay to pump groundwater. In the area east of Oakdale, where agricultural is expanding on groundwater, that current cost is approximately $80-$100 per acre foot of pumped water, depending on depth to water. While the market is easy to define, there is difficulty in educating locals that these markets, with a limited ability to pay, could require water rate increases to offset the lack of revenues if oversold to this market.

The End Game. The end game is to provide the maximum protection to the district's water rights. Meeting that goal may be best met by having equal participation of transferred water into each market area. Politically, this strategy may provide the broadest base support to any challenge of OID's water in the future.

OID is currently in negotiations and discussions with multiple parties regarding its marketing strategies going forward.

CONCLUSIONS

The true benefit of the WRP is that it has set a course of action for the OID. It has brought focus to an irrigation district and laid a path to meet the needs of a changing agricultural industry. If implemented as planned, the WRP will have provided the following regional benefits;

- Protected the OID's water rights
- Provided enhanced customer service opportunities to constituents
- Rebuild, modernize, and expand OID's water delivery infrastructure
- Protect the future water supply needs of the local urban areas
- Keep water rates affordable through a balanced effort of water transfers (50,000 acre feet) and allowing for agricultural expansion into OID's SOI (17,000 acre feet)
- Enhances local water supplies by 30,000 ac-ft
- Substantially increases water supply reliability and meets OID service needs in a worst-case drought

WATER RESOURCES PLANNING — ARE YOU READY?

Steve Knell, P.E.[1]

ABSTRACT

Oakdale Irrigation District (OID) is a 72,345 acre irrigation district located in the northeast foothills and valley floor of the San Joaquin Valley of Central California. In late 2004 OID embarked on the development of a Water Resources Plan (WRP) with a subsequent adoption of the Plan in June 2007. The planning document and subsequent environmental review took nearly two and half years to complete. Oddly enough, the time spent developing the WRP was just about equal to time spent positioning OID to begin the planning process, hence the point of this paper. Water resource planning is not something one should embark upon lightly. It is an expensive process to do correctly; it is demanding in its time and energy commitment from the district; it is politically risky or at best politically challenging, depending on your local situation, if the groundwork is not laid properly.

There are a number of elements a General Manager and/or an irrigation district Board of Directors should consider, or be aware of, prior to investing substantially in such a planning effort. Without a good understanding of the critical path elements to get to a successful implementation of the WRP a district could spend a sizable amount of money and staff time on a planning effort that ends up becoming largely un-implementable.

This paper will discuss experiences learned at OID regarding its efforts in implementing a successful Water Resources Plan.

INTRODUCTION

“Fail to plan, plan to fail”, is a saying that has been around for quite awhile. It’s a good saying and in 6 words captures the essence of where irrigation districts should be, or need to be, with respect to planning their water futures.

OID took on the effort to plan its water future in 2004 with the release of a Request for Proposals to develop a Water Resources Plan. Years before getting to that point however, there was a concerted effort by the board of directors and general manager to identify and assess some critical path hurdles. Those hurdles included:

- Laying the Foundation
- Constituents
- Board
- Management
- Employees

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PRE-PLANNING YOUR PLANNING

Strategic Business Plan-Laying the Foundation

Planning an irrigation district's water future is just a subset of its overall business plan. A business plan is the foundation from which subsequent planning efforts should evolve. Until an irrigation district board and its general manager are in sync in the identification of their key business objectives any attempts at ancillary planning outside that need are at risk of being unsuccessful.

Case in point: OID had embarked on and developed the following planning documents since the early 1980's; a Master Plan for System Improvements in 1983; a Water Conservation Master Plan in 1991; a Groundwater Management Plan in 1995; and an Agricultural Water Management Plan in 2000. While good money and good intentions were the basis for each of these planning efforts, none of these planning efforts were ever implemented. Why the lack of success? Generally, systemic limitations in the organization's culture precluded it from moving forward as is outlined below.

In May 2002 OID embarked on the development of a Strategic Business Plan. There were lots of reasons to embark on yet another planning effort, all of which are captured in the *Forward* of the *Strategic Business Plan*;

> "There were several reasons for the preparation of this plan at this time. A new General Manager and relatively new Board wished to refocus the organization on the strategic issues affecting its future. For many years high turnover both in management and at the board level had produced confusion and inconsistent directions in the minds of the staff and the public. New financial resources have recently become available to carry out expanded plans. Before plunging into the future, the board felt that a review of the organizations direction and purpose was needed. Also importantly, OID's traditional methods of water delivery, management and customer service may need to be updated or adjusted going into the future. Multiple types of customers, and customer needs, changes in best farming practice that require less water and management of pollutant runoff, and new water resource management responsibilities may require OID to reevaluate their historical practices."

As further stated in the *Forward*;

> "The confusion of the past years has diminished the motivation and ability of the staff of the organization to plan and accomplish longer term objectives. OID staff is well aware of their internal handicaps and of the worn out state of OID facilities. Better vision, purpose and morale must be restored before strategic objective can be accomplished. This is the biggest challenge for the new leadership."

During the development of the Strategic Business Plan there was an identification of the weaknesses of the “old” district and, more importantly, a path forward to correct those weaknesses. Input into the performance measures, vision and goals for OID came from the Board, management, its staff, and more importantly, the public. The end product from this one year effort in conducting employee interviews, public interviews, water customer interviews, Board workshops, news articles and the like resulted in a product that had both organizational and public support upon completion.

Embedded in the Strategic Business Plan was the development of a Water Resources Plan. With the foundation block for the water resources planning being laid the next challenging hurdle could then be addressed.

Constituents

OID has a 300,000 acre foot water right to the Stanislaus River. OID began selling, through water transfer contracts, 41,000 acre feet of that water to municipal and environmental recipients beginning in 1998, about 4 years prior to the developing its Strategic Business Plan. During that 4 year period, as a result of those transfers, there were 3 General Managers that had come and gone, 2 successful recalls of Board members and one Board member who ran for re-election and lost. To say the least, water is a controversial subject in the OID water service area.

The public vetting during the development of OID’s Strategic Business Plan went a long way in testing the waters regarding the public’s willingness to discuss all aspects of water issues. The thoroughness of the needs assessment of OID as it related to protecting its water, its financial needs, infrastructure rebuilding and modernizing needs, etc, went a long way in informing the public. This process was not done well for the original water transfers and the resultant turmoil of this shortcoming was a benchmark lesson for the new Board and General Manager. There was not a desire to repeat the mistakes of the past.

Constituent buy-in is essential for any actions of an irrigation district contemplating enhanced management, planning or transfers of water. Taking the time to build that buy-in via a non-threatening format, such as development of a strategic business plan, is a great opportunity for an organization to build bridges within the water community. While one won’t be able to lead all the horses to water to drink, the object is to be in a position that if one or two kick, it won’t hurt too badly.

For purposes of the remainder of this paper we will assume that the idea of constituent involvement and participation will be a central focus of all related actions involving water. Whether it is plan development, vision or mission changes, or implementation of measures that change the water culture for your district the public involvement is critical.

THE THREE LEGGED STOOL

Typically, the organization chart for an irrigation district has the Board of Directors at the top of a pyramid. Next on the pyramid are the General Manager and legal Counsel(s). Underneath that layer comes a management team followed by the general workforce and bulk of employees. Conceptually, lay the pyramid on its back and place the Board at one point, the GM and his management team at another point and the employee component at the last remaining point. This vision will be used later in the discussions.

Assessing the End Game

The end game for development of a water resources plan is its implementation. So there are two actions necessary here; one is development of the plan; and the other is the plan's ultimate implementation. At some point an irrigation district needs to ask itself, if it develops a plan does it have the means to implement the plan? If the answer is no, you're not ready, nor should you begin the planning effort.

As pointed out earlier, OID had no problem generating plans from 1983-2000; it had a problem implementing them. Generally, a plan's failure to be implemented is the result of a weakness in one or more of the stool legs envisioned earlier. Both "development" and "implementation" subjects will be discussed further in each of the following subjects.

The Board Leg of the Stool

Generally, public policy moves forward on a majority vote at the irrigation district governance level. Not surprisingly, that's the same number of votes it takes to discharge a General Manager (GM). The point here; the idea of water resources planning, the idea of changing the "water culture" in an irrigation district, if not done correctly, can have a downside for management. A GM needs to assess the readiness of a Board of Directors to tackle what could be a difficult subject matter politically, both as it relates to development of the water resources plan and its implementation. There will be some very hard choices that need to be made by this collective body and that ability to make those hard choices should be up front and center as an irrigation district moves into planning its water future.

The advantages of promoting the development of a Strategic Business Plan are twofold. One advantage is that it's an easy sell to the Board and public. Businesses need business plans and the benefits afforded during the business plan's development with respect to information gathered outweigh the cost of the business plan by a significant multiplier. A second benefit is that it affords the GM an opportunity to assess and flesh out the sensitivity of a Board of Directors in many subject matters, not just water resources. That understanding can go alone way to test the Board's stomach for change.

OID went into the development of its Strategic Business Plan on a 2-2-1 swing vote by its Board of Directors. One new director, not sure of the purpose for the planning effort thought it was a good idea for the money spent. The outcome, a year later, was a strong

3-2 vote to move forward in implementation of change in many business arenas for OID, including the planning of its water future.

The Management Leg of the Stool

The management team at an irrigation district is comprised of the General Manager (GM) and his Management Team. The Management Team is usually comprised of Department Heads over a variety of operational segments of an irrigation district, which at OID today include Finance, Engineering, Contracts, Construction & Maintenance (Support Services), and Water Operations.

General Managers usually come to be general managers in one of two ways; they "grow up" in the organization through promotions and advancements to a position of authority (i.e., Department Manager) and at the point the current GM leaves are promoted into the vacated GM position. A second way a GM comes into an irrigation district is via an outside solicitation from the irrigation district. In the former, the GM pretty much knows the professional capabilities of his management team because he has worked with them for a number of years. In the later, a GM generally inherits his management team and has a bit of a learning curve regarding their professional capacities. In either case, the management team needs to be of a technical and professional caliber to both develop and implement a water resources plan. Not having that team in place, or having a less than strong team, is a weakness in the stool analogy.

Assessing both the capabilities and capacity to perform of the OID management team during the development of the Strategic Business Plan was a great help at OID to the new General Manager. The result of the Strategic Business Plan's development showed that the weaknesses of two existing Department Managers could not be overcome by training or education. While great individuals, who served the past purposes of their employer well, they did not possess the knowledge, skills or ability to move the district forward into or through the technical requirements of implementing a modern day resources plan. Through agreement, they were retired out from the organization, and replaced with individuals with suitable skills.

The Employee Leg of the Stool

The importance of the employee leg of the stool is an often overlooked element to the successful development and implementation of a water resources plan. Much like the Board of Directors and the Management Team, a weakness in the capabilities of irrigation district employees is a recipe for a failure to implement any plan.

An analogy I used often is when the old ditchtenders back in the 1930s were told that they would have to give up their horses and start driving vehicles to make their water deliveries. Many had to go and get drivers licenses, take tests, learn mechanics, etc. to adjust to the change. Similarly, when a thing called a telephone was put in their offices so they could communicate more often and more quickly with not only their supervisors but with customers, all new adjusts came into being. Those employees either learned these new skills or moved on to other careers.

Today we are at a point no different. Ditchtenders are being told that computers will be installed in their trucks. Many ditchtenders at OID didn't even own home computers but now had to learn a new skill. Accurate gate deliveries, water accounting, SCADA, automated gates, remote site controls, etc.; it is a continually changing process for demands on employee skill sets. Employees either learn to adapt, step up and get additional training, embrace the change, or move on to other careers. For management, the hard part can be the "moving on" piece.

At OID, during the mid to late 1990s, low wages and low hiring standards created an organization ill equipped to meet the challenges of an upcoming and modernizing irrigation district. In 2003, a concerted effort was made to implement change in the workplace, to give employees who wanted to be challenged, who wanted a career, a place to stay. Those employees not interested in such an organization were encouraged to leave. Of the seventy-two (72) employees currently at OID forty-one (41) have been hired during the last 10 years. Nine (9) of the 41 are new positions, six (6) were hired to replace retirements. The resultant twenty-six (26) replacements were employees who "moved on" to find more compatible careers.

Those hard choices back then have made OID a responsive and progressive organization today. The quality of workmanship produced and the caliber of the employees in the work force at OID make it a community asset to Oakdale and earned it Business of the Year in 2010 from the Chamber of Commerce.

CONCLUSION

The coming political and societal climate for water is one that will demand water to be managed at a high level. To get there on the macro level is, or should be, the primary responsibility of those serving in a stewardship role over that resource. In the west, that's generally an irrigation district. To assert that resource management role the development of a Water Resources Plan is an agencies statement regarding its water future. It serves as a public statement that its mission and direction to meet the challenges of the future are sufficiently managed.

The key to successful implementation of a Water Resources Plan have been outlined herein from a case study from the Oakdale Irrigation District. This is a district that has gone through the challenges of building the foundation for change, implementing change and advancing the modernization of its water delivery system. It is hoped the experiences learned and shared within this paper will provide food for thought to those about to embark on a similar journey.

WATER RESOURCES PLAN - UPDATE

As a result of the successful development of its Water Resources Plan, OID went forward in 2009 and bonded for $32 million to do some large scale water conservation and infrastructure rebuilding projects. Those series of projects will be finished in 2012 and the revenues used to repay those bonds will be funded with water transfer revenues.

METHODOLOGIES FOR ANALYZING IMPACT OF URBANIZATION ON IRRIGATION DISTRICTS

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Guy Fipps, Ph.D., P.E.[2]

ABSTRACT

The region of Texas along the Mexican border has been experiencing rapid urban growth. This has caused fragmentation of many irrigation districts who are struggling to address the challenges resulting from urbanization. A previous paper provided an analysis of the growth of urban area and its impact on water distribution networks in five Texas border counties over the ten year period, 1996 to 2006. In this paper, we discuss alternative procedures developed to assess such impacts, and we evaluate their effectiveness in identifying critical areas, growth patterns, etc.

Urbanized areas were identified starting from aerial photographs using two different approaches: manual, and automatic based on the analysis of radiometric and structural image information. The resulting urbanization maps were then overlapped with distribution network density maps, and critical impact areas were identified. This paper compares the results obtained between the different methods, and evaluates if the analysis can be further improved by categorizing the urban area with the Morphological Segmentation Method.

INTRODUCTION

Texas is predicted to have the fastest population growth in the USA between 2010 and 2060, and the Rio Grande Regional Water Planning Area (Region M), which is one of the 16 Texas Water Planning Regions established by Senate Bill 1 in 1997, is predicted to have the highest growth in Texas, with +182% (Texas Water Development Board, 2012). Within Region M, Hidalgo and Cameron are the most populated counties, with an expected growth of +103 and +164%, respectively between 2010 and 2060 (Rio Grande Regional Water Planning Group, 2010).

Urbanization in South Texas is causing the fragmentation and loss of agricultural land, with detrimental effects on normal operation and maintenance of districts (Gooch and Anderson, 2008, and Gooch, 2009). In particular, districts have to abandon structures and invest in new ones to ensure proper operation, change how to operate systems when canals become oversized, and increase rates to address the challenge of reduced revenues from water sales. Districts in this region primarily operate their systems manually, with a canal rider personally moving from site to site. As a consequence, urbanization can create access to and maintenance of facilities difficult or more time consuming. Transfer of

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water rights from agricultural to other uses reduces the total amount of water flowing through the water distribution networks, which typically decreases conveyance efficiency and increases losses. Finally, the increasing presence of subdivisions and industrial areas in the vicinity of the delivery network increase the liability for canal breaks and flooding.

Most districts in the region do very little analysis of the effects of urbanization on their operation and management procedures, or incorporate urbanization trends into planning for future infrastructure improvements. Therefore, there is a need for identification of critical areas. There would be several benefits from such analysis, for example identify priority areas for conversion from open canal to pipeline (Lambert, 2011).

The objective of this paper is to compare alternative procedures and techniques to assess urbanization impacts on irrigation districts and to evaluate their effectiveness in identifying critical areas.

Literature review

Several methodologies have been used to identify urban area extent and growth. Many studies use satellite archive imagery as source of data (e.g., Landsat) which are becoming more readily available, are characterized by a multi-spectral data, and have good spatial resolution for landscape scale analysis. When analysis is carried out on smaller areas, results can be more accurate using aerial photographs, which provide more detail on geometric information. Analysis of imagery data for interpretation of land use and land cover dynamics can be performed with manual (Bonaiti and Fipps, 2011) or automatic procedures. The most utilized automatic approaches are Pixel-Oriented (PO) and Object-Oriented (OO) analysis. In the last decade, several studies demonstrated that the OO method can give more accurate results compared to PO (Pakhale and Gupta, 2010).

Urbanization maps identify only the location of urban areas. To interpret the evolution of spatial patterns, Ritters, et al. (2000) proposed a model which distinguishes different types of forest fragmentation through an automatic pixel analysis of aerial photography. Ritters’ analysis is used to determine the progressive intrusion of urbanization, classified into categories: edge, perforated, transition and patched. Vogt, et al. (2007) and Soille and Vogt (2009) proposed an improvement in Ritters method by analyzing the fragmentation on the base of image convolution, called the Morphological Segmentation Method. This method helps to prevent misclassifications of fragmentation and can be easily applied using a free software (Soille and Vogt, 2009, GUIDOS, 2008).

Impact on districts can be measured not only with the size or the type of urbanization intrusion in their service area, but also with a specific analysis of the interaction between water distribution network and urban expansion. Little attention has been given to this aspect (Gooch, 2009)

MATERIALS AND METHODS

Study area

Six counties along the Texas-Mexico border have irrigation districts with Texas Class A irrigation water rights. Our analysis was carried out on the three southern counties of the basin: Cameron, Hidalgo, and Willacy (Fig. 1). These counties contain 28 irrigation districts with a total service area of 759,200 acres, and a canal system 3,174 miles long.

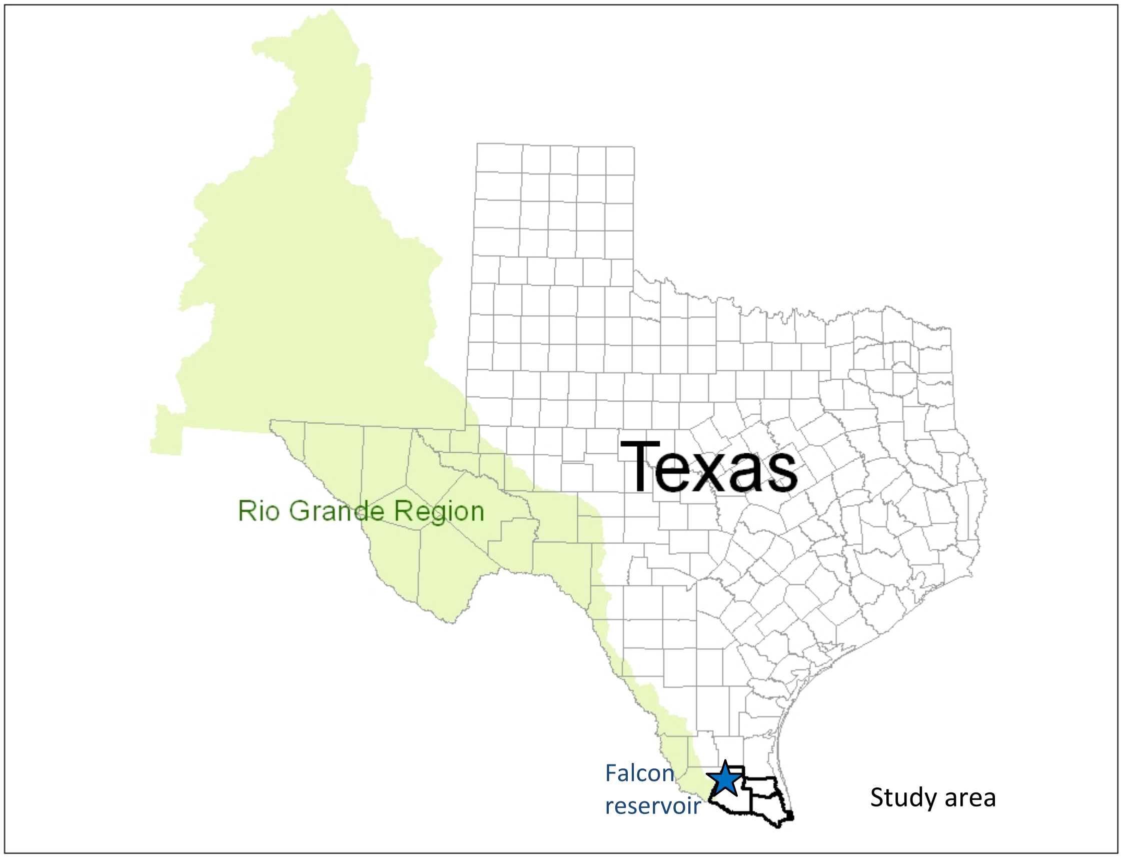


Figure 1. Location of the study area

Urbanization Maps and Network Fragmentation Index

Methods for obtaining Manual Urbanization Maps (MUM), Buffered Manual Urbanization Map (B-MUM), Network Fragments (NF) and fragmentation indexes (Network Fragmentation Index, NFI, and District Fragmentation Index, DFI) have been discussed in Bonaiti and Fipps (2011). The creation of automatic urbanization maps was done using the eCognition software, which is based on an object-based image analysis method. We called them Automatic Urbanization Maps (AUM). Since the preparation of aerial photography is time consuming, we applied the methodology only to the South Eastern portion of the Brownsville Irrigation District (BID) for the year 2006. The method was also applied to the area inside the city limits. This method is faster and gives higher detail compared to MUM, but since it is based on a slightly different approach (e.g., all houses are included) consistency between the two methods must be evaluated.

Similarly to what done with MUM, we added 0.03-mile buffer to AUM to create a Buffered Automatic Urbanization Map (B-AUM). Then we overlapped it with open canals and pipelines and we identified "automatic" Network Fragments (NFa). Finally, we applied the Kernel density to NFa and we obtained the "automatic" Network Fragmentation Index (NFIa).

<u>Morphological Segmentation Method</u>

In order to add information to the urbanization maps, we categorized them using the Morphological Segmentation Method. The categories that are defined by the procedure are: Core, Edge, Perforation, Bridge, Loop, Branch, Islet. We used the GUIDOS 1.3 software (Vogt, 2010). In particular, the software implements the Morphological Spatial Pattern Analysis (MSPA) and allows modification of four (4) parameters as described in the MSPA Guide (Vogt, 2010):

- *Foreground Connectivity: for a set of 3 x 3 pixels the center pixel is connected to its adjacent neighboring pixels by having either a) a pixel border and a pixel corner in common (8-connectivity) or, b) a common pixel border only (4-connectivity). The default value is 8*
- *Edge Width: this parameter defines the width or thickness of the non-core classes in pixels. The actual distance in meters corresponds to the number of edge pixels multiplied by the pixel resolution of the data. The default value is 1*
- *Transition: transition pixels are those pixels of an edge or a perforation where the core area intersects with a loop or a bridge. If Transition is set to 0 (↔ hide transition pixels) then the perforation and the edges will be closed core boundaries. Note that a loop or a bridge of length 2 will not be visible for this setting since it will be hidden under the edge/perforation. The default value is 1*
- *Intext: this parameter allows distinguishing internal from external features, where internal features are defined as being enclosed by a Perforation. The default is to enable this distinction which will add a second layer of classes to the seven basic classes. All classes, with the exception of Perforation, which by default is always internal, can then appear as internal or external (default value equal to 1)*

We applied the methodology to B-MUM, B-AUM, and AUM. We used default values for the four parameters except for the Edge Width with AUM, which was set to 10 to account for the smaller pixel size of this map. To be suitable for the software, the original files (shapefiles) had to be first converted to raster. To do that, we chose a cell size that looked reasonable for the type of detail of the original map. Therefore we used a cell size of 310 for B-MUM and B-AUM, and a cell size of 31 for AUM.

Based on the idea that network fragmentation has a different impact on districts operation according to the category that overlaps it, we also set up a procedure to correct the NFI using a categorization map. Using the 1996 B-MUM, we gave the following weights to categories: 1, 2, 3, 4, 5, and 10, respectively for Core, Edge, Bridge, Loop, Branch, and Islet (no results were obtained for the Perforation category in our maps). In other words, we assumed that the impact on district operation is greater if a new subdivision overlaps a canal in a remote area, where district personnel and farmers are not well organized to adapt to such changes. Using the Raster Calculator ArcGIS tool we multiplied the category weights by the NFI, and then normalized the results based on the maximum value. We called the result the Corrected Network Fragmentation Index (NFIc).

Network Potential Fragmentation Index

To avoid the burden of extracting NF and then combining them to urbanization maps to obtain NFI, we tested a simplified procedure based on a probable number of NF instead of the measured one. We first created an Urban Fragments Density Map (UFDM) by calculating the density of urban fragments in the 1996 MUM (i.e., the number of isolated urbanized polygons per area unit). To do this, we applied the "Feature to Point" ArcGIS tool to the urbanization polygons and then the "Kernel Density" tool to the resulting point map. In both cases we used default values. Secondly, we created a Network Density Map (NDM) by applying the "Line Density" tool (with default values) to canals and pipelines. Using the "Raster Calculator" tool, we multiplied the UFDM values by the NDM values, and then normalized the results based on the maximum value. We called the result Network Potential Fragmentation Index (NPFI). In analogy with DFI, we finally calculated for each district a District Potential Fragmentation Index (DPFI). This was done by calculating the ratio between the sums of NPFI pixels values and the total length of canals and pipelines.

RESULTS

Urbanization Maps and Network Fragmentation Index

Urbanization analysis using Manual Urbanization Maps (MUM) showed that in the Lower Rio Grande Valley the urban area increased at an average of 31% from 1996 to 2006, and that the urban area within districts increased at an average of 45.2%.

In Figure 2 we compare the urban areas identified with the manual (MUM) and the automatic (AUM) methods. Major urbanized areas are identified with both methods. Unlike the MUM, AUM identifies individual buildings rather than urbanized area (Fig. 3). Overlap to canals and pipelines of buffered maps (B-MUM and B-AUM) was performed only outside the city limits. We obtained a different number of network fragments (NF and NFa) in the two cases (Fig. 4). Although the highest values of NFI and NFIa are located in different areas, the two major areas of fragmentations are identified with both maps (Fig. 5). Figure 6 shows NFI as obtained overlapping B-MUM to canals and pipelines in the entire study area.

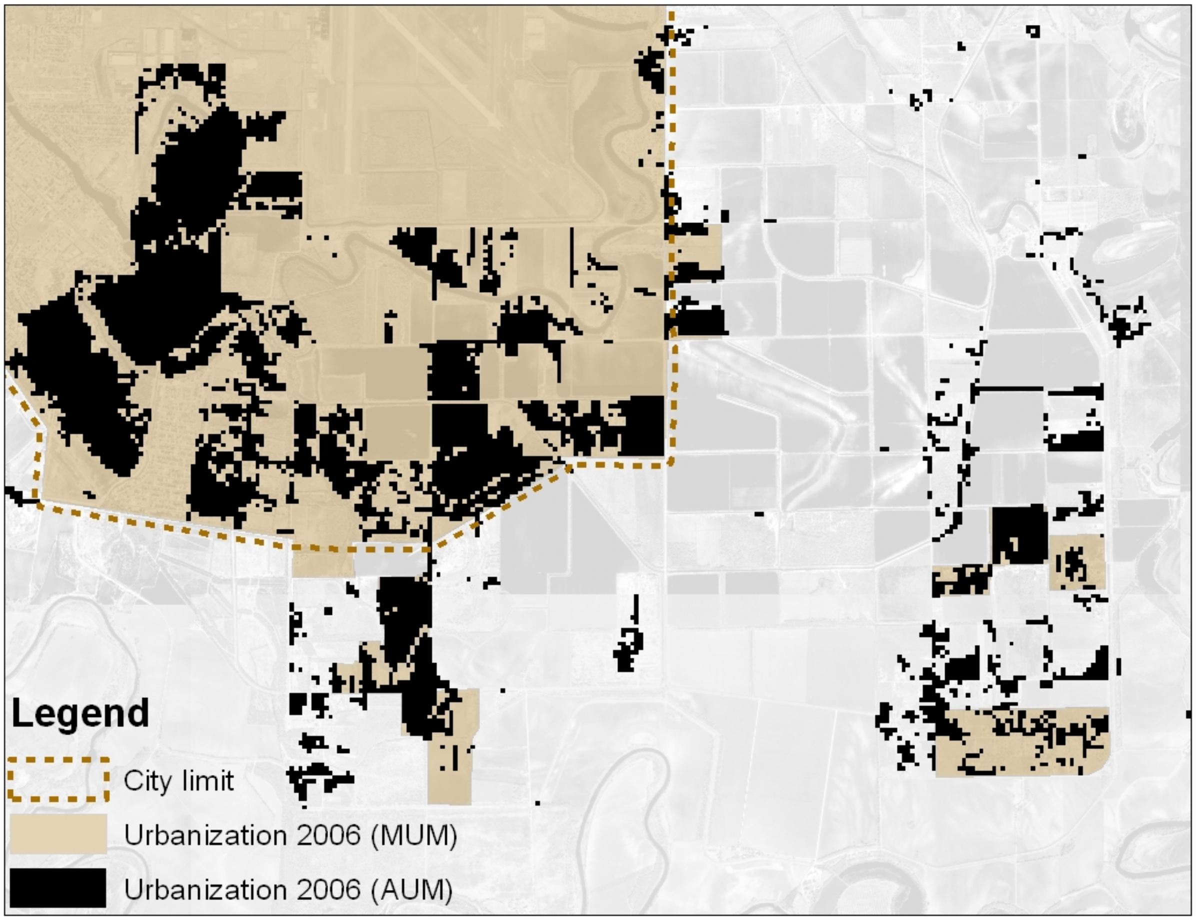


Figure 2. Identification of urban areas with the manual (MUM) and the automatic (AUM) methods, in 2006

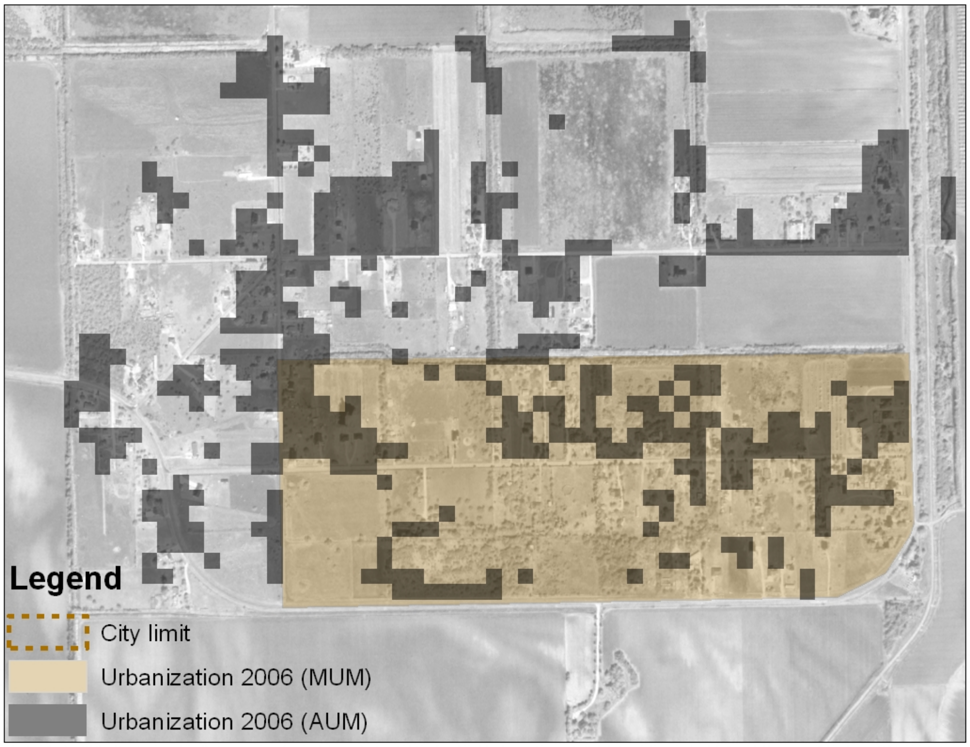


Figure 3. Detail of urban areas identification done with the manual (MUM) and the automatic (AUM) methods, in 2006

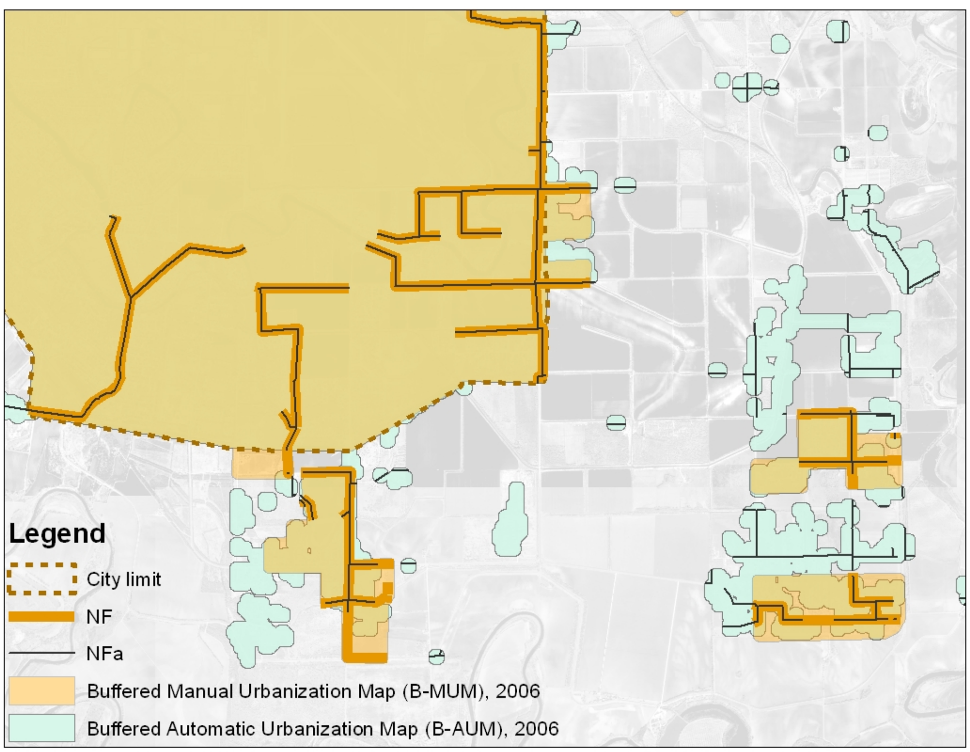
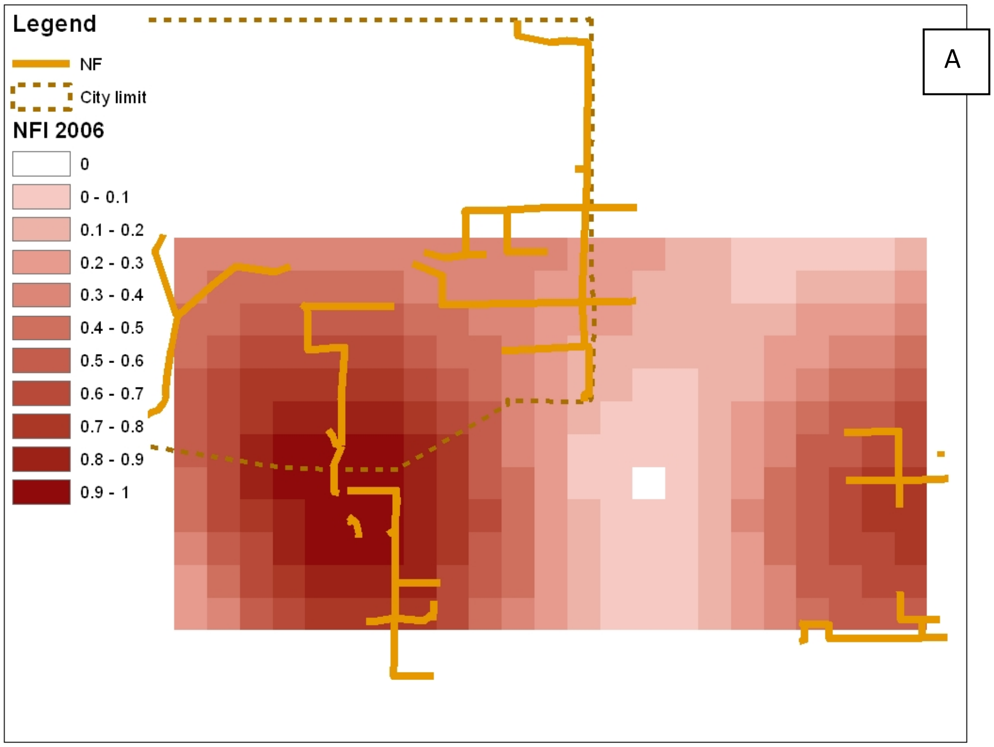


Figure 4. Fragments of canals and pipelines obtained by overlapping manual and automatic buffered urbanization maps (B-MUM, B-AUM) in 2006. Fragments (NF, NFa) are determined only outside the city limits.



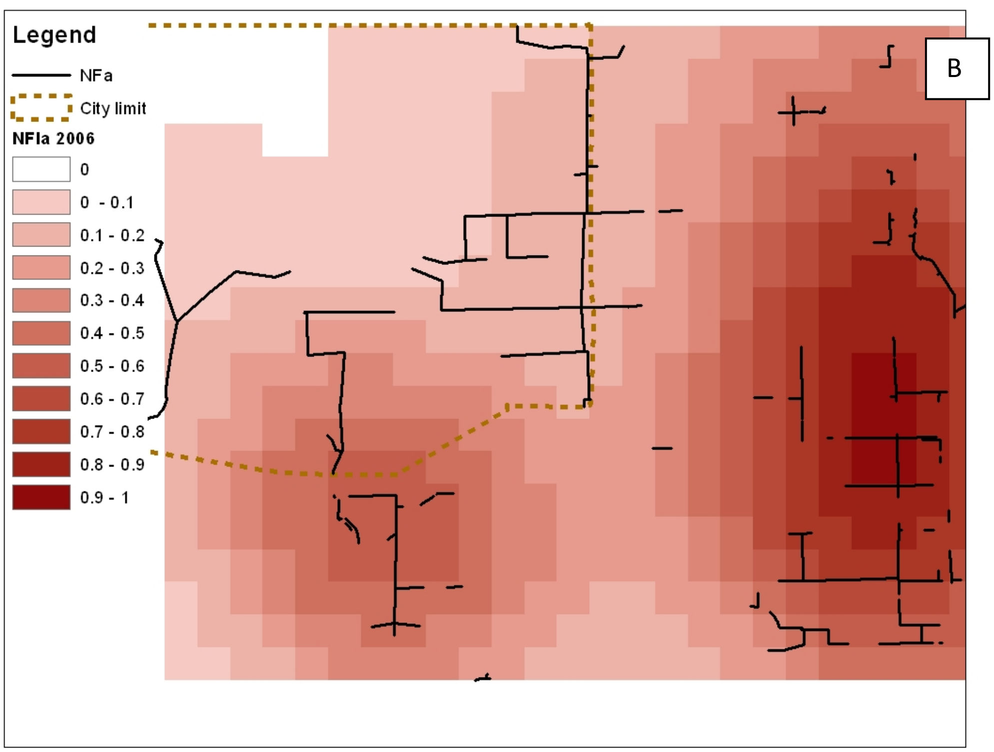


Figure 5. Network Fragments and Network Fragmentation Index calculated for the year 2006 using buffered urbanization maps. A) Using B-MUM (NF and NFI); B) Using B-AUM (NFa and NFIa)

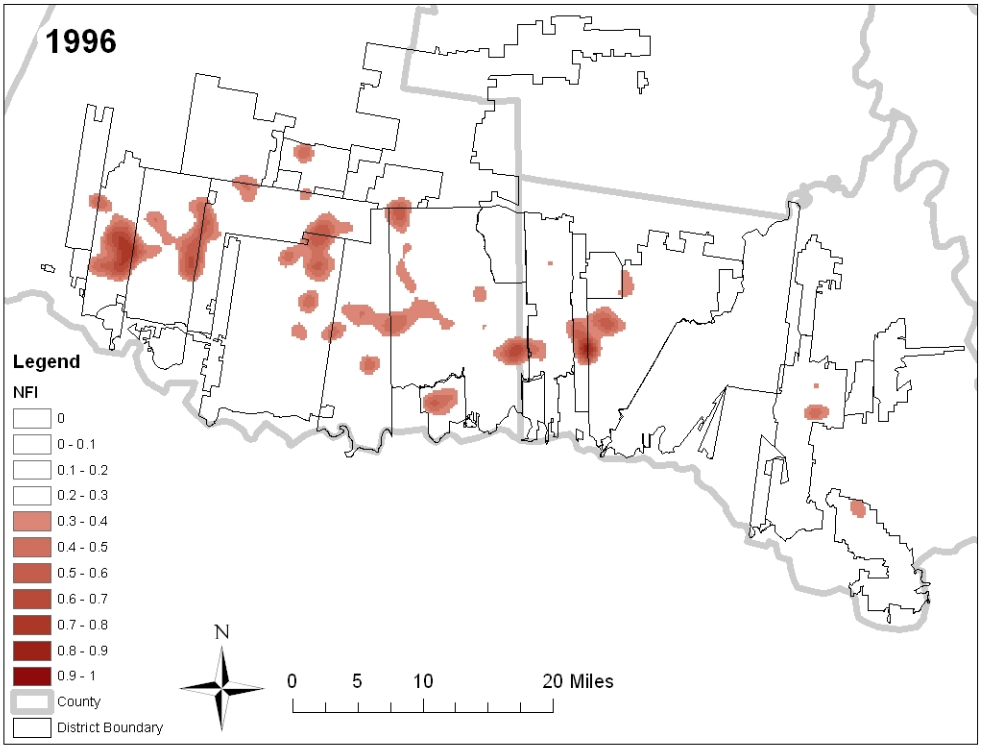


Figure 6. Network Fragmentation Index, shown as a density map, in the year 1996 using B-MUM. Only values >0.3 are shown, for easier identification of areas with higher fragmentation

Morphological Segmentation Method

Categorization was found to be useful in highlighting specific urban areas. As an example, Bridges and Loops (red and yellow) identify areas that will be likely soon completely urbanized, while Branches and Islets (orange and brown) those most isolated (Fig. 7).

Figure 8 shows the results of categorizing different 2006 maps. Some areas are classified differently when using B-MUM or B-AUM (charts A and B). For example, the urban area close to the city Core is classified as Islet in the first case, while Branch in the second case. When using a non buffered map, such as AUM, results are completely different due to the higher map definition (pixel is 10 times smaller) (chart C). This chart shows categorization being performed also inside the city limits.

Figure 9 shows the main steps of calculating a corrected NFI (NFIc) using the 1996 categorized B-MUM. As a result of applying weights to categories (chart B), NFIc is higher in remote areas compared to NFI. By showing results as density map, and excluding values <0.3, we were able to better identify the most affected areas (chart C).

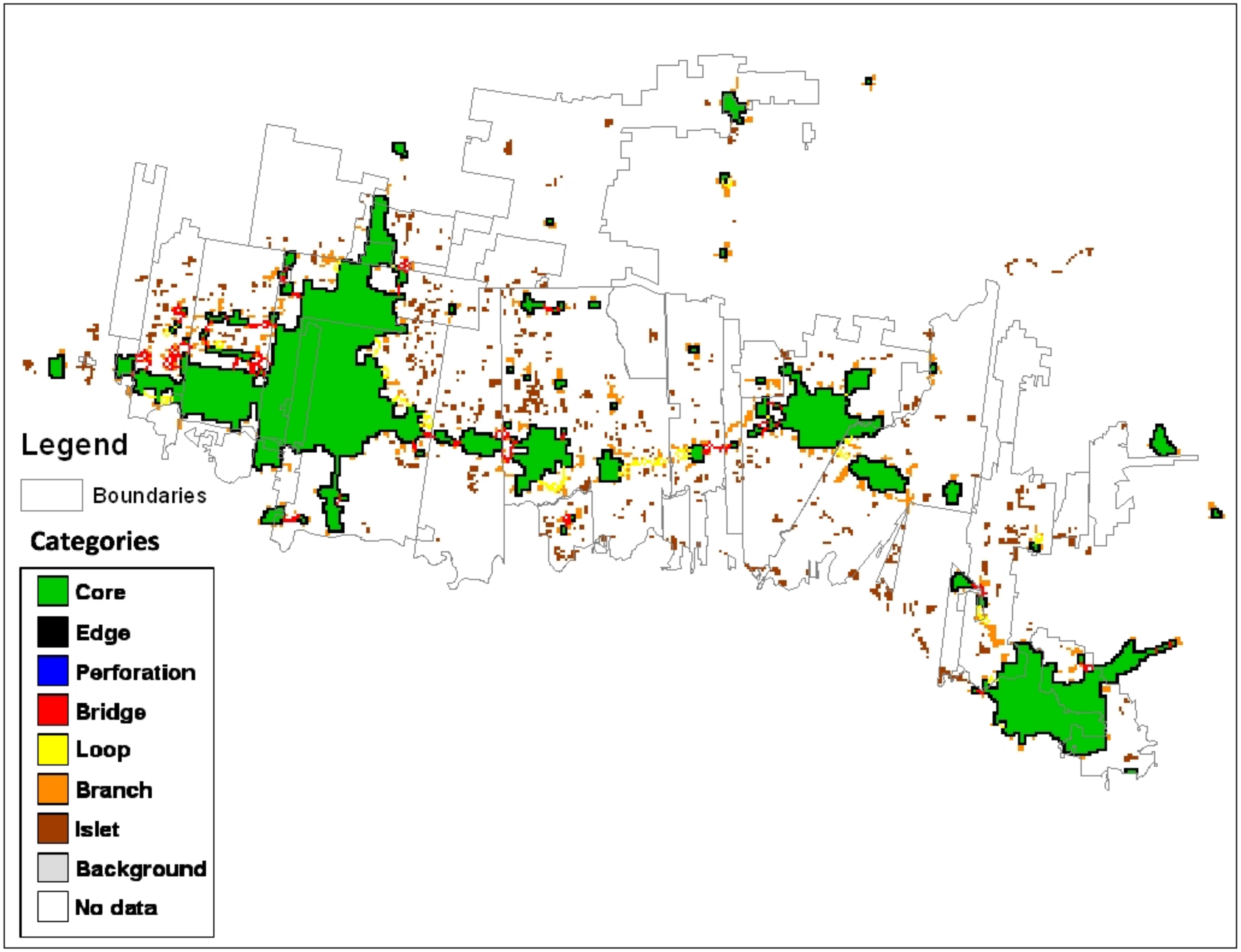


Figure 7. Categorization of 1996 Manual Urbanization Map (MUM) using the Morphological Segmentation Method.

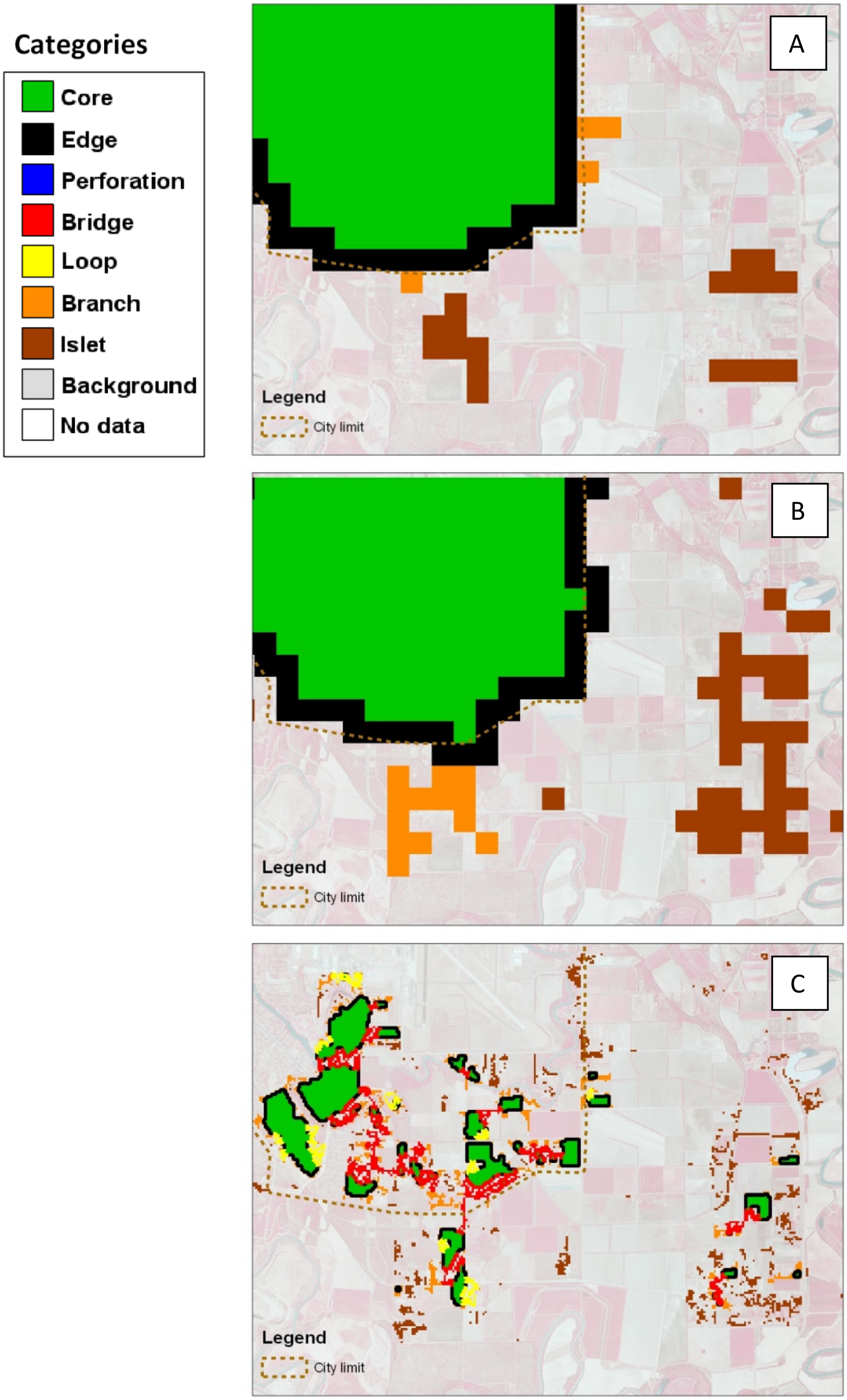


Figure 8. Categorization of 2006 urbanization maps using the Morphological Segmentation Method: A) B-MUM with cell size 310; C) B-AUM with cell size 310; D) AUM with cell size 31 (also area inside the city limit is analyzed).

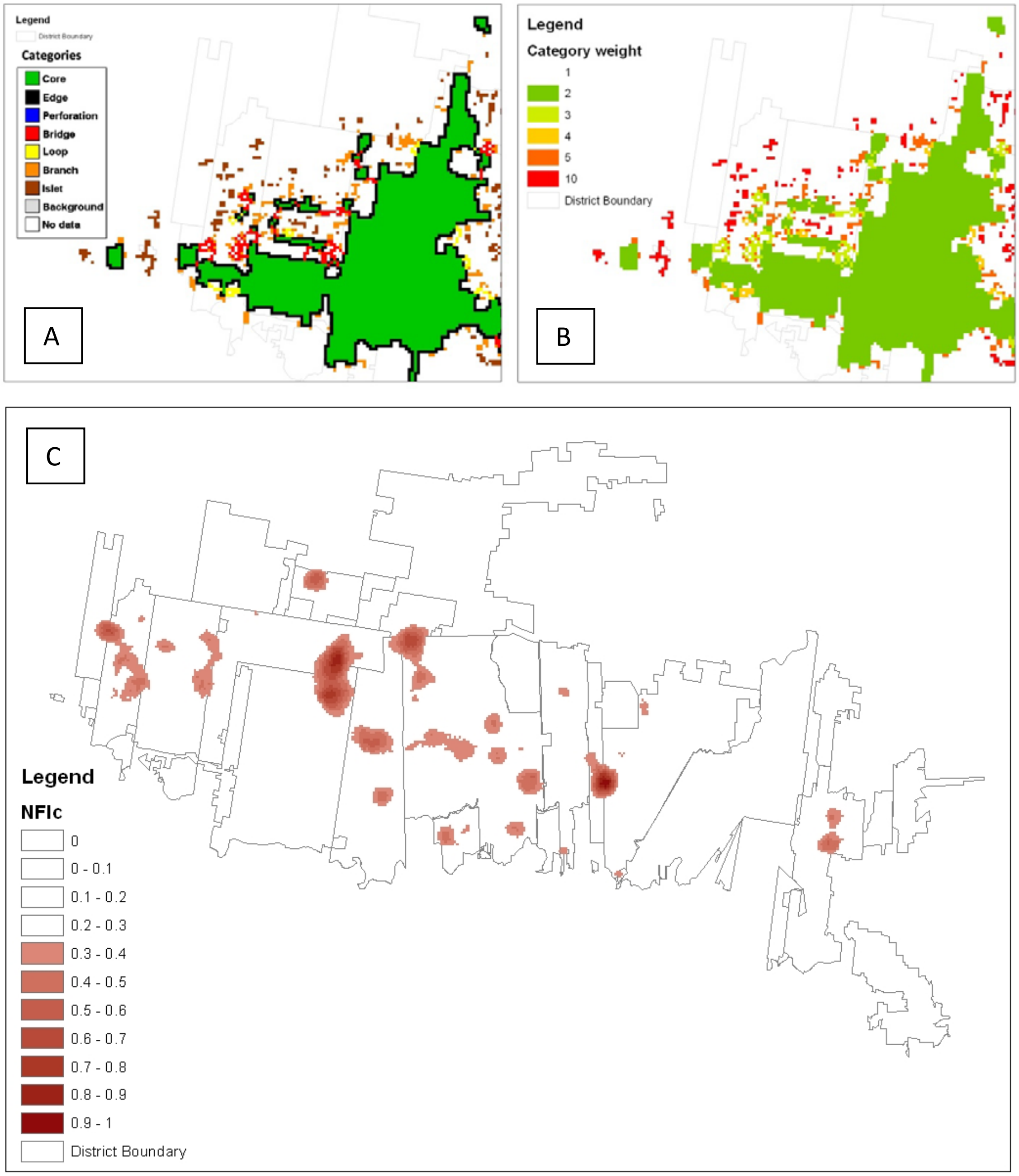


Figure 9. Steps of calculating a corrected NFI (NFIc) using the 1996 categorized B-MUM. A) Example of categorization of B-MUM; B) Example of weights assigned to categories; C) NFIc (only values > 0.3).

Network Potential Fragmentation Index

As shown in Figure 10, UFDM has localized areas of high fragmentation, whereas NDM (canals and pipelines) is pretty uniform with few areas with higher density (charts A and B). The combination of the UFDM and NDM gives a NPFI similar to NFI, despite the very different method utilized (chart C). Also DPFI resulted comparable to DFI.

Figure 11 shows that results are very different if NPFI is calculated using various elements of the distribution network (e.g., open canals and pipelines, or only open canals). It would be interesting to evaluate which case maximizes the correlation between NPFI and the impact of urbanization on district operation.

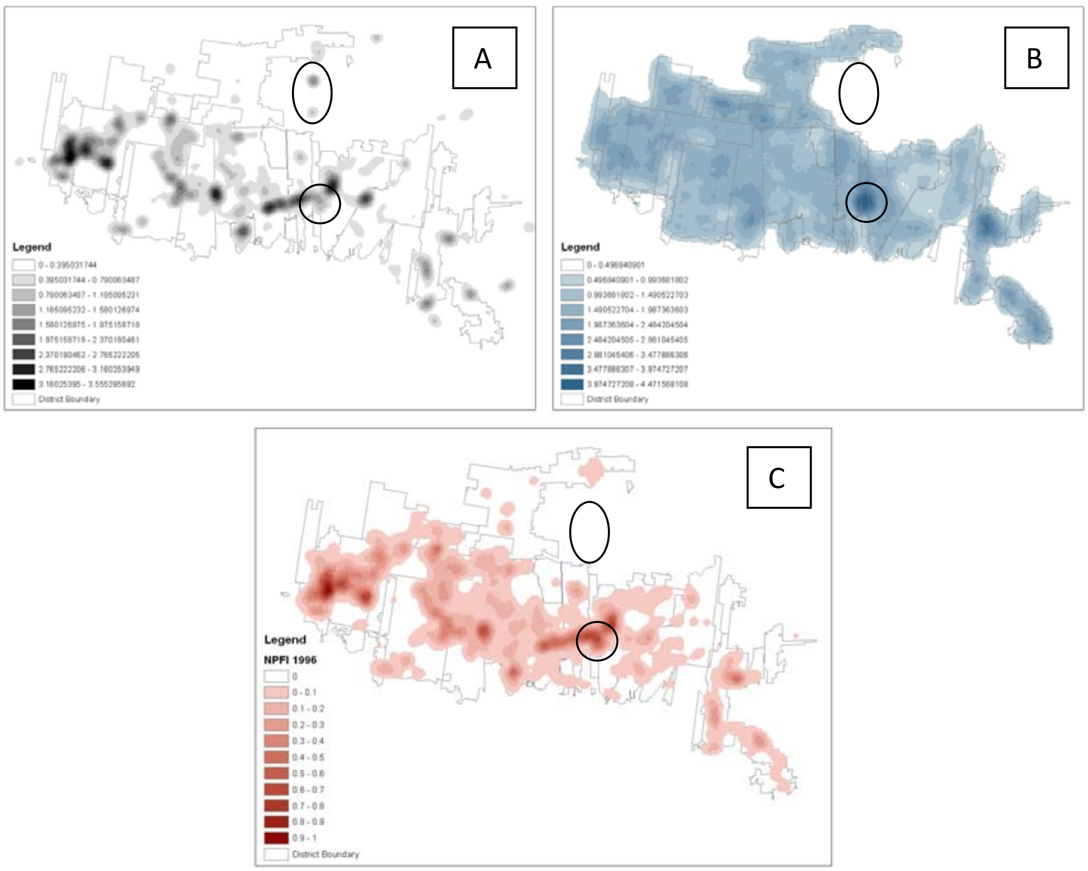


Figure 10. Steps of calculating a Network Potential Fragmentation Index (NPFI): A) Urban Fragments Density Map (UFDM) for 1996 MUM; B) Network Density Map (NDM) for open canals and pipelines; C) NPFI. Circles show examples of differences among charts.

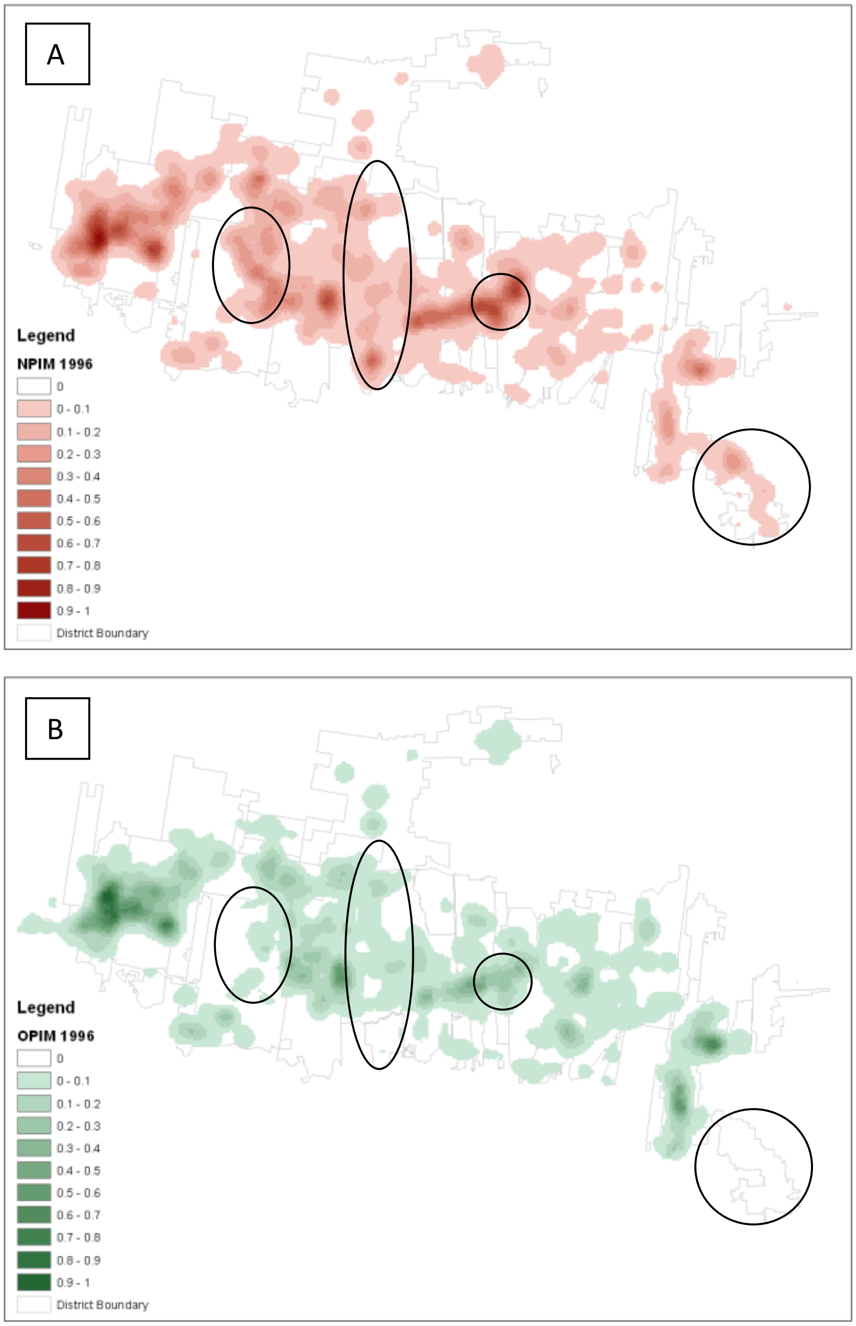


Figure 11. NPFI for different elements of the water distribution network in the year 1996. A) Open canals and pipelines; B) Only open canals. Circles show examples of differences between charts A and B.

CONCLUSIONS

Methodologies were presented to interpret the fast urban growth dynamics in the Lower Rio Grande Valley of Texas. The two methodologies proposed for urban areas identification, manual and automatic, gave good results, both being able to accurately identify urbanization. Although a test on a larger area would be beneficial, results showed that Automatic Urbanization Maps can replace Manual Urbanization Maps, as the image processing phase is less time consuming. We can estimate that while the manual procedure required weeks of processing, the automatic one took only few days.

The use of synthetic indexes helped identify areas where the water distribution network is impacted by urbanization. Although highest values of Network Fragmentation Index were located in different areas when calculated from Manual and Automatic Urbanization Maps, the major areas of fragmentations are identified with both maps.

Interpretation of urban fragmentation dynamics was improved by using categories defining the type of urbanization. By assigning weights to such categories, we obtained a corrected Network Fragmentation Index. The set up of a simplified procedure to calculate impact of urbanization (Network Potential Fragmentation Index) showed potential for application, even if analysis was based on probability of fragmentation rather than observations.

Recommendations for future work include:

- Identify correlation between analysis results and observed impact on district operation, especially when applying weights to urbanization categories
- Identify which elements of the distribution network have more impact on district operation when fragmented (i.e. open canals, pipelines)
- Further evaluate the advantages in term of computation of automatic analysis

ACKNOWLEDGEMENTS

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SOCIO-TECHNICAL ASPECTS OF WATER MANAGEMENT: EMERGING TRENDS IN CENTRAL ASIA

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Peter Mollinga [2]

ABSTRACT

Water sector during the soviet period has been protected from the financial and political uncertainties due to overwhelming state presence in the sector. The firm trademark of Soviet water management was technology-technical oriented, hierarchical institutions in the sector which are centrally controlled by communist party and water sector ministries. Ideological and political protectionist policies of the soviet government have been crucial on shaping water sector policies. The water management decisions at the different levels were not contested by any of involved parties (different republics, sectors, territories) due to integrated economic structure and strong presence of the state in everyday politics, including in water management. However, collapse of the Soviet Union has brought many uncertainties, political and economical changes, and decline in social infrastructure into former republics. The water sector became playground for multiple actors at the different levels and arenas, making water management a socio-political process. This paper is an attempt to describe how three different dimensions of water management in Central Asia are interacting and shaping each other: local, national and inter-state.

INTRODUCTION

Societal problems are multi-faceted and complex. For instance, natural resources management (NRM) has several components and dimensions that influence each other. The solution to NRM problems requires an understanding of both natural resources systems and their interactions with human (management) systems (Mollinga, 2009). Multi- dimensional societal problems require changing the "business as usual" approach on natural resources management (NRM) research, especially on water resources management. The response to growing NRM problems, particularly in the water sector of the Central Asia has been one of "normal professionalism" (Chambers, 1988) of water sector researchers and engineers. "Normal professionalism" is a standard, disciplinary, limited response to problems, which is reproduced in the education system. This has contributed to the reproduction and continuation of problems and has been generating limited approaches for addressing water management problems.
Characteristics of an inter- and transdisciplinary approach to complex water resources management problems are the following. (1) acknowledges the complexity and heterogeneity of problems and organizations, (2) accepts local context and uncertainty, (3) implies interactive action and is inter-subjective, (4) is in most cases action oriented, making linkages across disciplinary boundaries (Mollinga, 2008).

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This is especially relevant for Central Asia, where water management in the past decades has changed from a centralized, purely technical issue to a debated and contested transboundary, socio- political endeavor (Dukhovniy. 2008, Abdullaev. 2000, Abdullaev et al. 2009). The disciplinary and government-directed research efforts from the Soviet period do no longer suffice for improving water management in modern Central Asia. The old approach no longer applies for the following reasons:

1. Due to the major geopolitical change of the collapse of Soviet Union, both governance and management of transboundary water resources between five countries became more of a political process. During Soviet times water management was regarded as purely 'technical'; the other dimensions were under strict control from a central point, Moscow, and in this sense given and unchangeable. With five sovereign states sharing the central Asian rivers, a new politics has emerged.

2. Post – soviet changes in agricultural policies have brought very serious social changes in rural areas. The ensuing social differentiation of the rural population has been captured by different research studies (Kandiyoti, 2003, Trevisani, 2008). Therefore, previous research on water management when collective farms were the main agricultural producers became irrelevant for today. The community of water users has become internally differentiated through the emergence of larger and smaller farms

3. The environmental consequences of the previous "hydraulic mission" (Allan, 2006) have been catastrophic for the region (Abdullaev et al., 2009). Therefore, research that speaks to a series of problems and concerns, including ecology, equity, and governance, beyond the concept of 'development' in the earlier soviet sense, is needed.

This paper presents a framework for socio-technical[3] analysis of water management and results of its application in the Khorezm region, Uzbekistan[4]. The main element of the framework is the boundary concept[5] "water control" (Mollinga. 2003, 2008) which was applied to capture three interlinked processes in water control: physical, organizational and socio-economic/political.

The water management in Central Asia has attracted attention of both mass media and politicians around the world since collapse of the Soviet Union. Initial interest to the water problems of the region was related to the "Aral Sea crisis"- environmental Armageddon of 20th century. The problem was outcome of decades long "fight" against nature, when water resources has been diverted from main rivers into millions of hectares of irrigated land to develop irrigated agriculture . After the collapse of the Soviet Union, Central Asian states have been very quick to confirm their commitment to keep Soviet

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[3] Socio-technical analysis was borrowed from Mollinga (2003) for describing two interlinked parts of water management systems: the first is infrastructure and the second is the human factor in managing water.

[4] This research has been conducted within the framework of the BMBF (German Ministry of Education and Research) funded project *Economic and Ecological Restructuring of Land- and Water Use in the Region Khorezm (Uzbekistan): A Pilot Project in Development Research*.

[5] "Boundary concepts are words that operate as concepts in different disciplines, refer to the same object, phenomenon, process or quality of these, but carry different meanings in those different disciplines" (Mollinga. 2008)

era water allocation arrangements between states of the region. This was that time only way to keep piece and calm in already turbulent region. In the beginning this worked very well, states of the region have formed interstate organizations for coordinating water related issues.

The impacts of the socio-economic decline in 1990's have had long term implications for water sector. The level of funding for operation and maintenance of the large scale water infrastructure has been greatly declined. Earlier well paid staff of water management organizations started to leave water sector in hundreds due to low salaries and declined prestige of the water sector. The national states having great economic difficulties due to the re-building of nationhood has not been able always provide enough support to the water sector. These radical changes have been crucial for changing soviet type, centralized water management more to socio-technical process. Although, states in Central Asia still tries to have tight and firm control over the water management at the different hierarchical levels more and more water management becoming more of socio-political process.

At present water management in countries of the Central Asia could be characterized as quasi-state water management, with multiple dynamics: growing social dynamics at the grass-root levels and growing hydro political tensions at the regional (interstate) level. The different levels are interlinked, any changes in one level affects other two. Therefore, in this paper dynamics of the water management at different levels are presented in context of its impact on other water management levels. E.g., any changes at the hydro politics at the transboundary will have immediate impact on everyday politics of water management due to reduced flows or changes in water regimes of main irrigation and drainage systems. The national state policies will reflect those hydro political changes and will enforce new set of rules, orders in order to cope with emerging problems, e.g., attempts to introduce water saving irrigation for increasing water efficiency, etc. This enforcement brings changes again into everyday politics of water management. This is cyclic process and every time changes in one level bring changes into the next level. Therefore, those who work on transboundary water management issues should take into account this interrelated nature of water management.

METHODOLOGY AND CONCEPTS

The centerpiece of the research framework applied in this research is socio-technical analysis was borrowed from Mollinga (2003) for describing two interlinked parts of water management systems: one is infrastructure and second is human factor in managing water. The boundary concept[6] of "water control" (Mollinga. 2008) has been applied to link technical, managerial and socio-economic- political aspects of the water management (figure 1). Different dimensions of the water control are interlinked, changes in one dimension result changes in the other two (Mollinga. 2003, 2008). The

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[6] "Boundary concepts are words that operate as concepts in different disciplines or perspectives, refer to the same object, phenomenon, process or quality of these, but carry (sometimes very) different meanings in those different disciplines or perspectives. In other words, they are different abstractions from the same 'thing' " (Mollinga.2008)

border concept is applied for analysis of everyday water management, state policies and hydro politics.

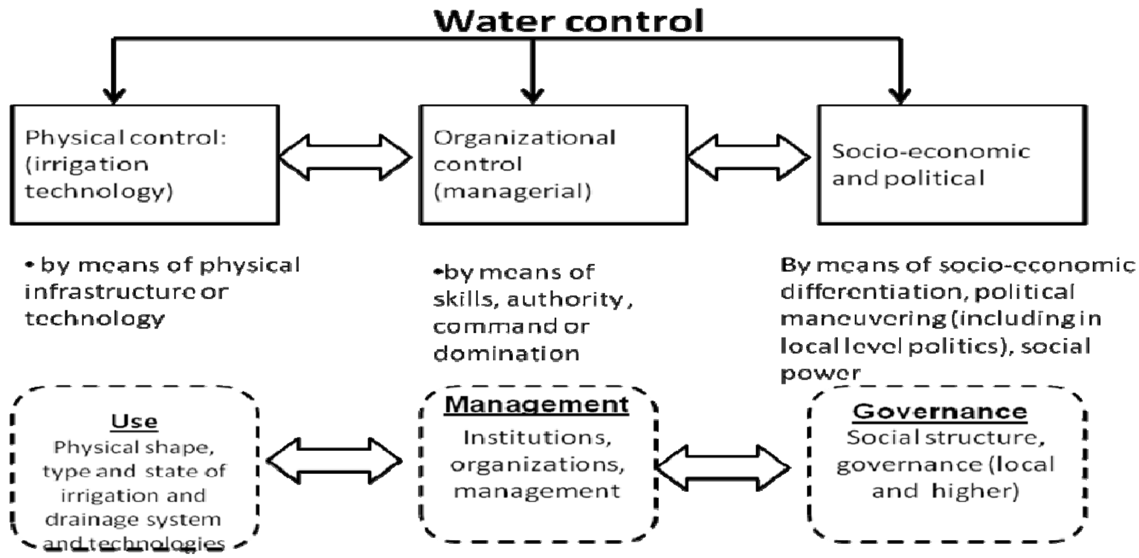

Figure 1. Water control (adopted from Mollinga .2008)

The socio-technical analysis has helped to look into the water management not only with eyes of engineer, but also link it with dynamic social structure of water resources management. The framework was applied for period of 2001- present times, when author have conducted extensive work on water management in the region (Central Asia). In this paper author applied water control concept into three levels of water management: everyday, politic of water policies and hydro politics of Central Asia. This is both interesting and challenging exercise the same time.

This concept was earlier applied for mainly to the everyday politics of water management (Mollinga. 2003). However, in this research the concept will be looking into those of three interlinked levels of water management in Central Asia. Three levels of water control: everyday water management, state policies and regional hydro politics are interlinked and shape each other. Everyday politics of the water management has become more of contested due to the multiple players and presence of state via different intermediaries, such as implementation of state quota (Uzbekistan, Turkmenistan), provision of subsidies (Kazakhstan, Turkmenistan) heavy presence of state officers (almost all states), the state policies on water management has been also dynamic although its central goal remains the same- keeping control over the water management at different levels. The hydro politics has been dynamic, transformed from being state centric during the Soviet times into more of dynamic and contested due to competing interests of independent states (figure 2). At three different levels common and connecting process is water control: this is the process of using, managing and governing of the water management for purposes of the economies.

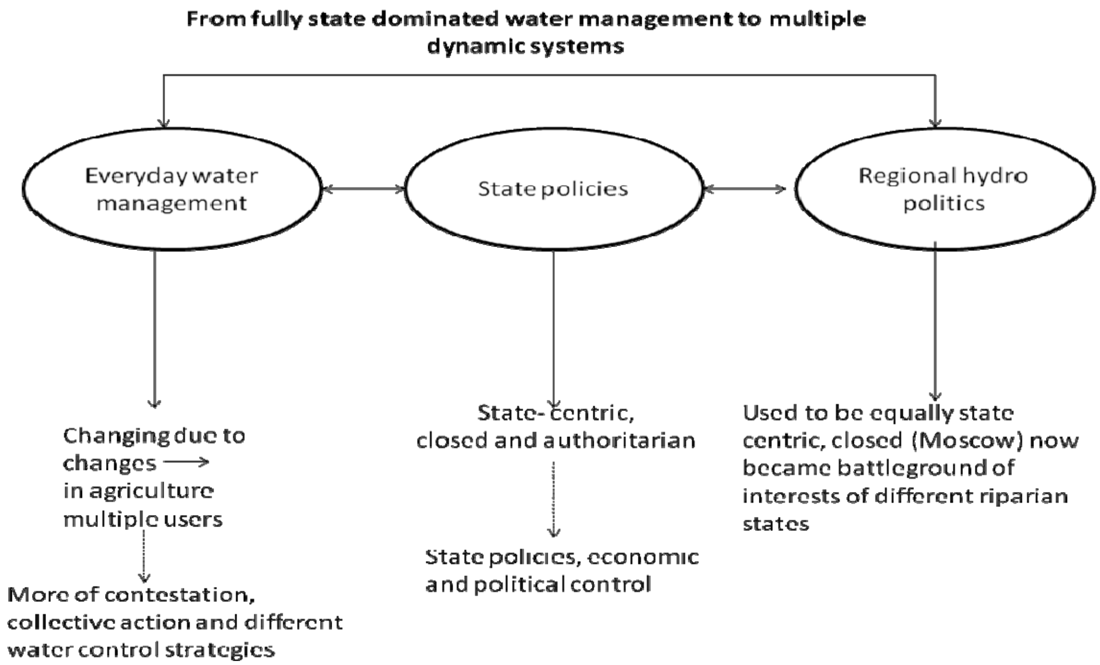

Figure 2. Water control at three levels of water management: everyday water management, state policies and regional hydro politics

The three dimensions of the water control (use, management and governance) differently reflected on three levels of water management (everyday, state and hydro politics). The everyday politics although has a governance dimension, it is overwhelmed by use and management dimensions, the state water policies are overwhelmed by governance, management and hydro political level by use and governance dimensions (figure 3). Therefore, application of the water control concept will consider these differences at the different water management levels.

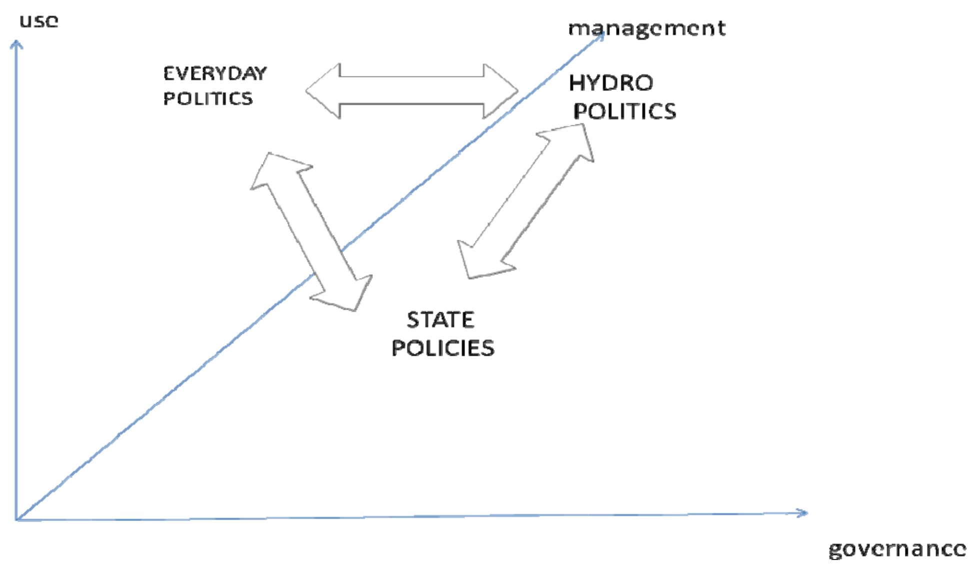

Figure 3. Three dimensions of everyday, state and hydro politics

The research on a water control at three different levels should highlight on-going processes and trends at each level. E.g., at the grass root level it is important to understand application of the water control strategies by different players, at the state level, it is to understand politics of state water policies and at the transboundary level, it is to research application of different water control strategies by different states as response to the changing hydro politics.

EMPIRICAL EVIDENCES: DYNAMICS OF WATER MANAGEMENT AT THE DIFFERENT LEVELS

Grassroots level (everyday politics) water management

The "everyday politics" of water resources management refers to the contested nature of day-to-day use of water resources (Mollinga.2008). The land use and management during the Soviet times was mainly in form of collective farms. The grassroots level of water management is that of former collective farm level where instead of large scale collective and state farms individual farming units has been formed during the 15 or so years of de-collectivization/individualization of agricultural production. Individualization of agricultural production system have resulted on more individual responsibilities and plurality of the production (Trevisani.2007, Veldwisch. 2008) which have resulted formation of different groups, stratification of community and society. This has been further exacerbated due to limitations of the water management system, which was designed to supply water for collective farming unit with centralized decision making (Veldwisch. 2008). Hence water distribution became an issue of social interaction, a place of contestation and competition (Veldwisch. 2008, Abdullaev et al. 2006, and Wegerich. 2000). As result, different groups started to apply different water control (Mollinga. 1998, 2003) strategies for getting access (Ribot and Peluso.2003) to the water at the former collective farm level. The result of this had been seen on water distribution: it became unequal both spatially, between uses and users (figure 4).

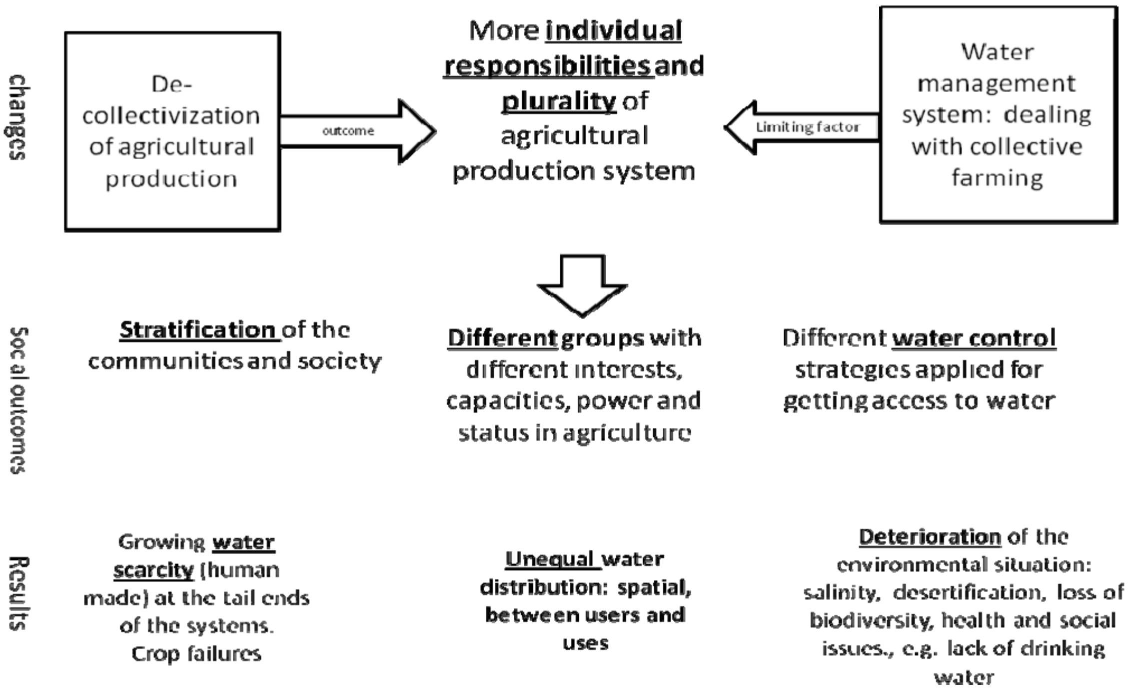

Figure 4. Dynamics of water management at grass roots level (Abdullaev at al. 2008)

Unequal water distribution result on growing water scarcity (human made) at the tail end of the irrigation systems leading to frequent crop failures (Abdullaev et al.2006, Wegerich. 2000). The social and environmental consequences of this has been growing salinity, desertification, drying of lakes and decline in biodiversity at the tail end of irrigation systems (Molden et al.2007). The grass-root water management became more of socio-technical rather than state- overwhelmed techno-technological process. The pressure of the changes at the grass root levels has been transformed into next level of water management- national level water policies.

State level policies (Politics of water policy)

The politics of water policy refers to the contested nature of policy processes at the level of sovereign states (Mollinga. 2008). As Rap (2007) describes it for the example of Mexico, the water policies, like other policies, are negotiated and re-negotiated in all phases and at all levels. Immediately after its independence some states of Central Asia have tried to sustain presence in agriculture (Uzbekistan, Turkmenistan) with consequent state- overwhelmed water management for irrigated agriculture but Kazakhstan and Kyrgyzstan where state in the beginning have left alone agricultural production solely to the producers. However, later (sometimes in mid 2000s) all states of the region have returned in different forms back to control of agriculture in different forms. The water management policies for agriculture shaped and influenced by states role in water management for different sectors: agriculture, energy, etc. The water sector is considerably re-shaped by nation building notion of the different states. The sectoral reforms, institutional changes brought more pressure on water management, mostly reducing flow of financial means, changing previous leading position of the water agency. The states of the region are translating their national policies into everyday water management (grass- roots) decisions and into hydropolitics (inter- state). E.g., national food security, energy independence issues are translated into agricultural policies such as state quotas for cotton and wheat (Uzbekistan, Turkmenistan), price control mechanisms (Kazakhstan) and etc. which have impact on daily water management practices. Similarly the same state policies have a reflection on behavior of the countries in the meetings of interstate organizations, countries dependent on irrigation defends water allocation for summer months for irrigation, energy scarce countries of upstream (Kyrgyzstan and Tajikistan) are trying to develop their energy sector.

Interstate level (Hydro politics)

Hydropolitics is a phrase that has been coined in the literature on international water conflicts, (cf. Waterbury.1979; Ohlsson.1995 in Mollinga. 2008). Elhance (1999 in Mollinga. 2008) explains hydropolitics as "the systematic study of conflict and cooperation between states over water resources that transcend international borders." Immediately after the collapse of the Soviet Union, 5 Central Asian states have organized Interstate Coordination Water Commission (ICWC) and states of Central Asia agreed to continue with the principles of water allocation that had prevailed in the USSR (Wegerich. 2008). The interstate relations were and are constructed to serve political goal- ensuring stability and preventing conflicts in the region and of course to give enough space to water bureaucracies to deal with water sector separate from other sectors. However, at the end of 1990's different countries of the region started to bring their national interests into the discussion table. The energy interests of the upstream countries (Kyrgyzstan, Tajikistan) came into conflict with irrigation water for the tail end countries (Kazakhstan, Turkmenistan and Uzbekistan). The water management at the regional level (Central Asia) became more of hydro politics (Abdullaev.2009a). The factors which influences interstate hydro politics depends from agricultural reforms, irrigation policies, regional cooperation and other polices of riparian states. The states of the region are overwhelmingly using all forces: political (regional, international forums), economical (gas, oils supplies, etc) in order to achieve more control of water management at the interstate level.

CONCLUSIONS

Interstate water management in Central Asia is seen mostly through prism of interstate relations only, ignoring of inter-related nature of water management at different hierarchical levels. Analysis of the water management at grass-root, national policies and interstate levels shows that changes have taken place in each level for last 15 or so years. The changes mostly related to the in increased attempts on water control by different players: different water users (grass roots), sectors (national) and states (interstate). Therefore, hydropolitics at the interstate levels is camouflaged or open reflection of those inter-related nature of the water management at different hierarchical levels.

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DEVELOPMENT OF IRRIGATION SCHEDULING AT THE WHOLE FARM LEVEL

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Leo Espinoza[2]

ABSTRACT

The average cotton farmer in the Mid-South works with large numbers of fields. Different crops, soil types, and planting times complicate irrigation scheduling at the whole farm level. This is probably the main reason why many farmers still do not use the irrigation scheduling tools. Results of irrigation scheduling in different counties in Arkansas during the last five years show that a developed potential evapotranspiration (PET)-based irrigation scheduler is an effective at the whole farm level. Main tools of this method are evapotranspiration (ET) and rain gauges. Comparison different ET tools shows that the atmometer is better suited to farm irrigation scheduling purposes in terms of price, accuracy of data, easy installation, and monitoring. PET data of different atmometers installed in the same place may differ by 1.69 % from the average PET during a three-month period. Evaluating a water deficit level of the particular field is very important. Soil type, tillage system and field configuration may affect the water deficit level of the field. The field water deficit method helps to evaluate the soil moisture level between irrigation or rainfall intervals and to determine the next irrigation time.

INTRODUCTION

Irrigation is one of the main farm operations in maximizing crop yield. Irrigation practices have sharply changed since the sensor base remote sensing technology began offer new opportunities in measuring soil moisture, canopy temperature, and ET. Irrigation scheduling experiments in drip, furrow and pivot irrigation systems shows that soil moisture sensors, wireless internet connections, and scheduling tools have worked satisfactorily in experimental fields and in research stations where the number of fields is just a few. However, irrigation scheduling in whole farm level is different due to different conditions. The average cotton farmer in the Mid-South works with large number of fields, sometimes more than one hundred fields. Each field is divided into several irrigation sections. There are different, at least three soil types, two or more crops, and planting times. All of these factors complicate irrigation scheduling at the whole farm level. This is probably the main reason why many farmers still do not use irrigation scheduling tools. Finding an effective solution to this issue can help farmers to save water and energy resources by applying irrigation scheduling at the whole farm level.

According to the "Cotton Farming" magazine web poll, 86 % of respondents named drought as the main factor that had the most influence on the crop yield and quality potential in 2011. Another poll shows 62 % farmers prefer to increase irrigation acreages

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and 38 % of them prefer to improve drainage. Nevertheless, a very small percentage of farmers use irrigation scheduling methods today. Recommended scheduling tools are expensive, require a lots of field data and input them in the calculation tables. Therefore, creating simple, easy to use and inexpensive irrigation scheduling method is an important task.

MATERIALS AND METHODS

Irrigation scientists and farmers use several irrigation scheduling methods. One of them is based in field water balance. According to this method irrigation water and rainfall, supplied to the field, should be equal to or greater than evapotranspirated, deep percolated, and runoff water during the irrigation season. It is difficult to measure deep percolation and runoff water properly. ET is measured by different tools such as standard evaporation pans, weather stations, and atmometer or ET gauges. Some methods are based on calculating ET depending on air temperature for the particular months of the year.

Second option of the irrigation scheduling is based on measuring or monitoring soil moisture. By observing ground by hand push probe or kicking, we are in reality testing and evaluating the soil moisture. Soil moisture more exactly may calculated also by the gravimetric method. Sensor based soil moisture measuring tools improved irrigation scheduling methods. Industry supplies gypsum blocks, electrical and electromagnetic conductivity soil moisture sensors that could be used in irrigation scheduling.

Another irrigation scheduling option is based on observing plant development that may help to evaluating plant water stress. Plant observing, measuring canopy temperature or leaf water potential measurements give the information that could be used in irrigation scheduling.

According to the field water balance or check book method, the amount of existing and incoming water in the field should be equal to the amount of outgoing water. Existing water consists soil moisture which is depends on field water capacity. Incoming water includes rainfalls and irrigation water. Outgoing water includes ET, infiltration and runoff water. ET calculated through PET, which is maximum possible ET in sufficient available water source conditions: ET=PET*C, here C is crop coefficient. PET calculated by weather station data, standard evaporation pan, and atmometer readings. Accuracy of atmometers' readings found by comparing PET data all of these tools and group of atmometers installed in the same place of the field. We observing PET for a 24-hour period during the two months: Atmometers' data was taken at 7 AM, 1 PM and 7 PM. This allows compare PET differences during the morning, afternoon and night hours.

Irrigation water amounts were measured by the flow meters. Soil moisture in the fields was monitored by EC-5 Decagon soil moisture sensors, installed at 6 and 12 inches depths and also by gravimetric method. To determine the effective scheme of atmometers' and rain gauges' installation in the farmlands, 9 atmometers and 15 rain gauges, including 5 digital rain gauges, were installed in the fields of McClendon's farm, Lee County AR in 2010 (Figure 1). They covered about 10000 acres of cotton fields with maximum distance between atmometers is about 10 miles.

Arkansas irrigation scheduling program and UGA Easy Pan are used according producers' instructions. Arkansas irrigation scheduler program needs daily entering temperature data and rainfall amounts, choosing recommended water deficit level depending on planting date, crop and soil type.

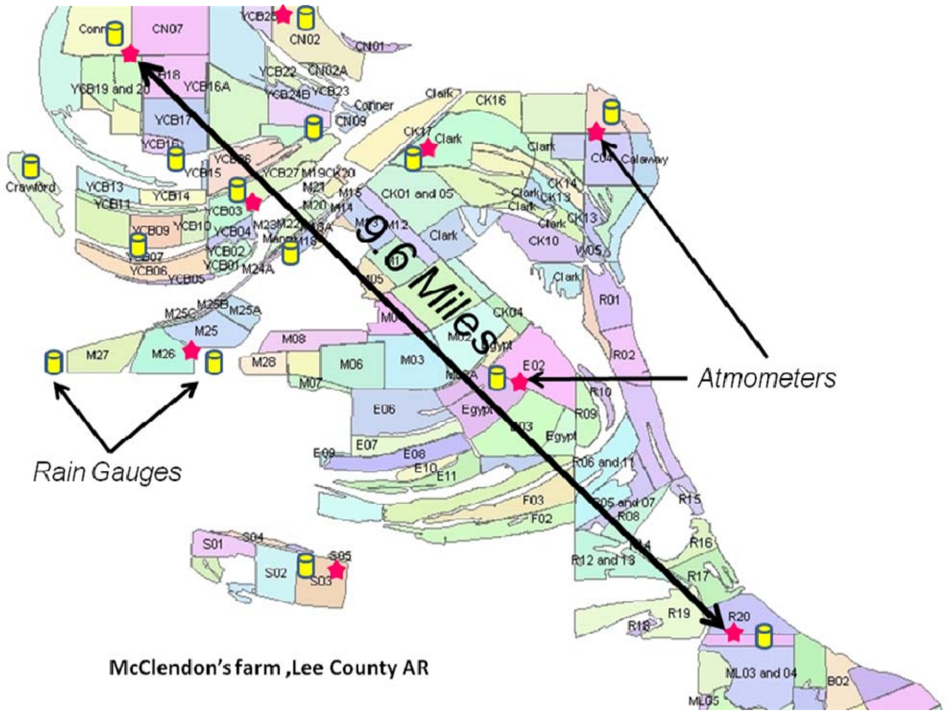

Figure 1. Map of installation atmometers and rain gauges

RESULTS AND DISCUSSION

The weather history in Marianna AR, during the last 50 years shows that yearly precipitation has varied from 32.7 to 73.5 inches. The ratio of maximum to minimum precipitations is 2.2. Summer precipitation differs more sharply; the same ratio here is more than 5. This means that summer rainfall may change many times from year to year. Summer precipitation trend almost is not changing for during the 50 years period. But in last 15-20 year period it has decreased significantly. Yearly precipitation trend has slightly decreased. Records show that now we have about an inch less precipitation than we had 50 years ago. The heat unit's accumulation during the summer time has increased in observing period. The trend of summer heat units has increased to 110 units in the last 50 years. This may be effect of global warming or result in local weather changing cycles. The fact is that weather is changing and we are getting hotter and drier summers.

How do farmers schedule irrigation? The survey provided by Cotton Incorporated shows that the majority of farmers schedule their irrigation by visual assessment. Just a few of them use irrigation monitoring tools.

We divided the irrigation options into four categories:

1. Farmer's experience
   - Visual assessment,
   - Weekly scheduling,
   - Taking cue from the neighboring farmers.
2. Monitoring soil moisture
   - Hand push probes,
   - Gravimetric method,
   - Tensiometers or Gypsum blocks,
   - Soil electric or electromagnetic conductivity sensors,
3. Monitoring plant development or crop appearance
   - Plant response to water deficit: plant height, width, biomass, color,
   - Leaf water potential: color or thickness,
   - Canopy temperature.
4. Field water balance or check book method
   - U of A Irrigation Scheduler,
   - UGA Easy Pan Irrigation Scheduler,
   - Using weather motoring tools: weather station, atmometer, and standard evaporation pan.

The first category is based on the farmer's experience. Many farmers use calendar-based irrigation scheduling or simply take their cue from the neighboring farmers. The second option is based on soil moisture monitoring. This ranges from simple ways of soil moisture measuring to sensor-based monitoring with wireless internet connections. This is one perspective of irrigation scheduling option, but is complicated at the whole farm level due to the large number of fields, sections, planting times, and crop and soil types. We may say the same thing about the third irrigation scheduling option, which is based on monitoring plant or crop appearance depending on water deficit. The fourth category of irrigation scheduling options is based on field water balance or the checkbook method. University of Arkansas irrigation scheduler program and UGA Easy Pan irrigation scheduler are based on this method. Field water balance method needs measuring PET by several tools like as weather station, atmometer, and standard evaporations pan.

We cannot exactly measure infiltrating and runoff water for the particular field of the farm. However, we may exactly measure or monitor ET through PET and crop coefficients. We can determine PET from weather station data, standard evaporation pan, and atmometer readings. Our experiments show that PET data found by these tools are close to each other, so we can use all of them in irrigation scheduling. 2011 field experiments show that PET data from the atmometer and weather station are similar even for long term usage during three months. Experiments also show that UGA Easy Pan PET data are also similar with weather station and atmometr's data for short term usage: during 10-15 days.

PET data from four atmometers installed in the same place of the field differ by just 1.69 % from the average PET data in a three-month period. These shows that atmometers are can give PET data with a sufficient accuracy for irrigation scheduling. A comparison of prices shows that the atmometer is better suited to farm irrigation scheduling purposes in terms of price, accuracy of data, easy installation, and monitoring.

Solar radiation causes PET. The Earth receives 340 W/m^2 of solar energy. Just less than half of this incoming solar radiation reaches the surface of the Earth. Half of this energy, or a quarter of the solar energy, is lost on evaporation. Consequently the evaporation and transpiration - ET is the main process that consumes solar energy. It plays a tremendous role in balancing Earth's surface temperature. Theoretically ET should be equal in the same parallels of the Earth. We compared PET in different parts of Arkansas about 135 miles apart from each other. Results show that the shapes of PET curves are similar for different parts of the state. If we put them on the same time table, then we can see just a little difference, probably due to local weather conditions—cloudy days, rainfall and temperature. For example, PET difference between Pine Bluff AR and Marianna AR is just 2 inches during the two months. It is interesting to note that PET in Pine Bluff was less than in Marianna or Edmondson even though Pine Bluff is more southerly than Marianna or Edmondson.

PET for a 24-hour period show (Figure 2) that PET mainly occurs in the daytime (92 %) versus nighttime (8 %). PET during the morning hours is less than in the afternoon hours. This is the reason why we may prefer night time irrigation, for example, with pivot irrigation systems to save significant irrigation water.

Is there a relation between ET and soil moisture? To determine this we compared the field water balance and soil moisture graphs. The field water balance includes infiltrated and runoff water. The field water balance and soil moisture curves are almost similar and parallel between irrigations and rainfalls. This shows that through field water balance or water deficit graphs we may evaluate soil moisture content between irrigations.

We recommend using irrigation notebook that helps better manage the farm irrigation. All field information, including the scheme of the irrigation sections and their watering times will be recorded in this notebook. To simplify the irrigation method we recommend creating a single irrigation table for the whole farm. The actual water deficit and irrigation events of the each field of the farm are represented with the two columns in this table. Actual water deficit is determined through the daily ET, crop coefficient and rainfall data. The water deficit level was chosen for each field depending on soil type, field configuration, and irrigation method. Pivot irrigation systems have less water deficit level than furrow irrigation. Every furrow irrigation method has more water deficit level than every other furrow irrigation.

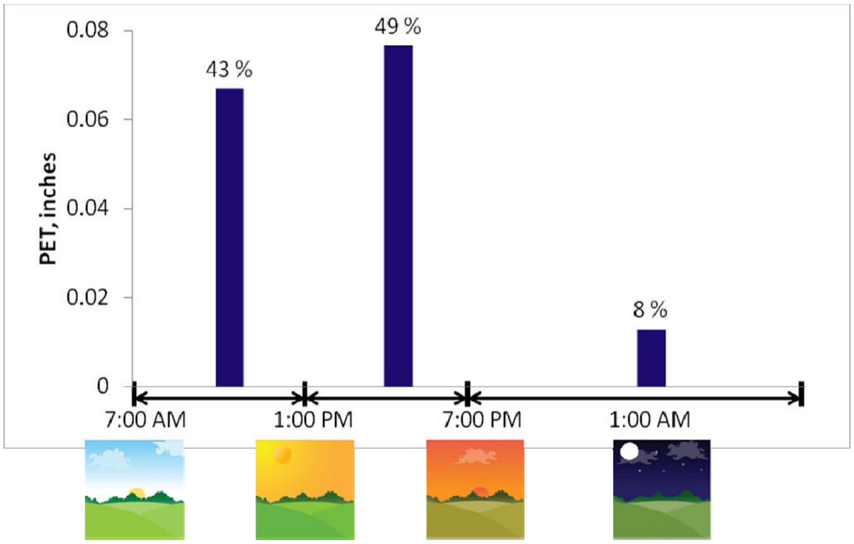

Figure 2. PET during the day.

Example of evaluating different irrigation scheduling options by the field water balance method is given in Figure 3. Rainfalls are shown as blue columns and irrigation events are shown as green columns in the diagrams. Soil type is silt loam and water deficit recommendation is 2.5 inches. The farmer six times irrigated this field in 2011. As seen from the graphs that the water deficit level is around an inch between second and third, third and fourth, and fifth and sixth irrigation events. This means that the soil was still wet before the next irrigation event in these intervals and therefore water use efficiency is low. Arkansas irrigation scheduler program recommends four irrigations for this field. However actual water deficit reaches more than 4 inches level between the first and second irrigations. Field water balance method based on actual atmomer's ET data recommends five irrigation events for this field. The distribution of irrigation events keeps the water deficit or soil moisture always at a uniform level that improves the plant development and water use efficiency.

ET readings of the atmometers show that difference between outlying atmometers is 1.29 inches and closest ones 0.56 inches in the end of the season. The statistical average of daily ET is 0.25 inches, this means that possible error from using remote atmometers may 5 days 3 hours. Therefore we may conclude that it is effective install at least one atmometer in 5 miles farmland distance. We recommend installing two atmometers for average farmer in Arkansas.

Rain gauge data are very different even for close fields. Even a small amount of rainfall may change the irrigation schedule. Results show that rainfall differences of the fields located more than three miles apart are significant. We recommend install one rain gauge in 3 miles distance in middle Arkansas area.

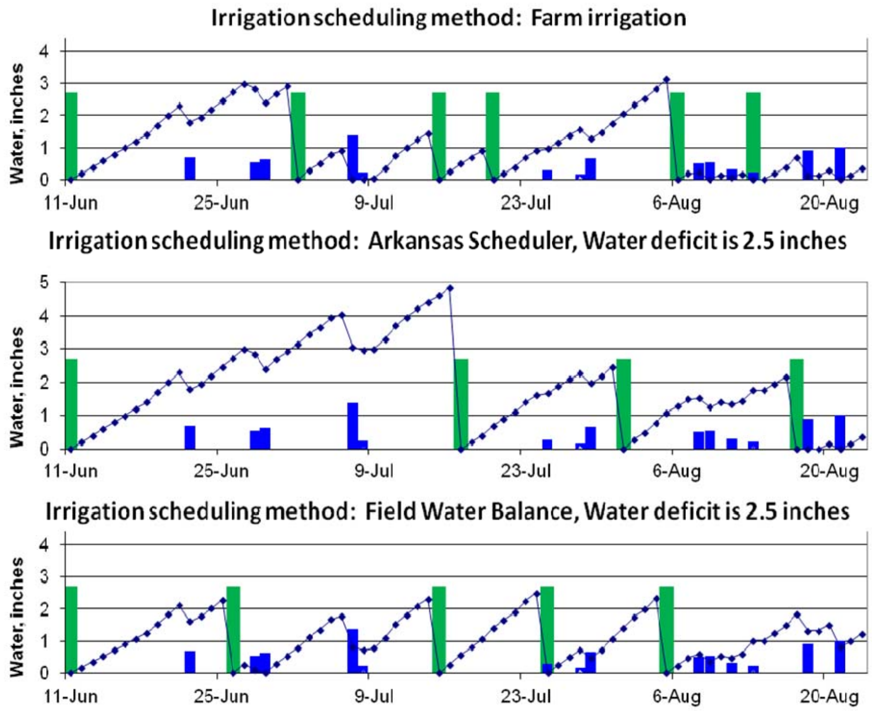

Figure 1. Results of different irrigation scheduling options.

CONCLUSION

The existence of large numbers of fields and dividing them into several irrigation sections, different crops, planting times, and soil types are complicating the use of the irrigation scheduling tools at the whole farm level.

The weather history in Marianna, AR, shows that the summer heat unit accumulations trend has increased about 110 units and yearly precipitation trend has decreased about an inch during the last 50 years.

PET data from weather stations, standard evaporation pan, and atmometers are similar. The atmometer is better suited to farm irrigation scheduling purposes in terms of price, accuracy of data, easy installation, and monitoring. PET data of different atmometers installed in the same place may differ by 1.69 % from the average PET during a three-month period. Experiments show that at least one ET gauge in 5 miles and one rain gauge in 3 miles will be effective in weather conditions in Middle Arkansas.

Field water balance or water deficit method helps to evaluate the soil moisture level between irrigation or rainfall intervals and helps to determine the next irrigation time for the field with given water deficit or capacity levels.

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