The Struggle for Efficiency — Actions and Consequences

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USCID
The U.S. society for irrigation and drainage professionals

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Preface

The papers included in these Proceedings were presented during the **USCID Sixth International Conference on Irrigation and Drainage**, held November 15-18, 2011, in San Diego, California. The Theme of the Conference was ***The Struggle for Efficiency — Actions and Consequences.*** An accompanying book presents abstracts of each paper.

The irrigation and drainage world is changing rapidly in response to both internal and external pressures. These pressures come from numerous directions, such as from new state and federal regulations, urbanization, changing on-farm irrigation practices and reduced water supplies.

Professionals in the industry are engaged in a **Struggle for Efficiency** when addressing these demands, and applying both new and established technologies. Policies such as volumetric allocations and tiered water pricing are commonly seen as desirable. Farmers use drip irrigation to conserve water on farm. **Actions** are implemented within an atmosphere of large uncertainty — such as eventual impacts of global warming, new environmental standards and FERC relicensing impacts. Furthermore, when these policies are implemented, the cost/benefit ratio may not be what was anticipated and there may be unintended **Consequences** — both good and bad, and local and basin-wide. The Conference provided a forum for presentation and discussion of these issues and others.

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-Chairs express gratitude to the authors, session moderators and participants for their contributions.

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CALIFORNIA'S NEW FOCUS ON WATER SUPPLY RELIABILITY AND SUSTAINABILITY

Steve Macaulay, P.E.[1]

ABSTRACT

This paper describes the increasing trend in California to address long term water supply reliability for both agricultural and urban water uses. More than thirty years ago an "era of limits" for natural resources was a popular point of dialogue with leaders in California state government. Since that time a realization of water supply limits has gained more traction, based on a combination of factors including: (1) conflicts between water uses and the environment, (2) a growing population, (3) a growing shift to high-value tree and vine crops, (4) the defacto reallocation of water from human uses back to the environment brought about by changes in law and regulations, and (5) increasingly stringent legislation requiring analysis and documentation of water supply reliability. Additional factors include continued groundwater overdraft in several major agricultural regions, environmental litigation that reduces supply reliability, and an apprehension of the potential impacts of long-term water supplies from a changing climate.

Major attention is being given to water supply reliability and sustainability throughout 2011. One current driver is development of a new plan for the Sacramento-San Joaquin Delta, often referred to as the hub of the state's water supplies. That new plan for the Delta is required by state law to address a more reliable long-term water supply for California. This paper provides current information on this topic, and the conference presentation will more directly address where this is heading regarding California water policy and regulations.

INTRODUCTION

The idea for this paper came from three sources. The first is experiences over the past twenty years in market-based water transfers during water shortages in California. Beginning in 1991, it became increasingly clear that some regions depended on water supplies from other regions to a higher degree during droughts. And yet there was no clear standard of water supply reliability for any region. The second source was the November 2009 water reform legislation in California, which among other things required that a newly-formed State agency "achieve the two coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem" (California Public Resources Code Section 29702(a)). The planning horizon for that legislation is through the year 2100, some ninety years into the future. The third source is the increasing attention to the subject of water supply reliability by key urban and agricultural water users, brought about by various threats to water supplies: regulatory restrictions, population growth, and increasing competition among water uses including the environment.

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Background

California is located on the west coast of the United States, and has a Mediterranean climate with warm dry summers and cool wet winters. Most of our rainfall is in northern California, and most of our population is in southern California. Our state's water challenges were an early focus following the addition of California to the United States in 1850. With the advent of gold mining and the expansion of agricultural irrigation, we faced serious challenges in getting the right amount of water to the right place at the right time. There was considerable conflict between mining and agriculture in California from 1850 to the end of the nineteenth century, characterized by changes in water right laws, development of water conveyance facilities, and initial development of storage facilities. As mining decreased, irrigated agriculture expanded to meet the needs of a growing population. Much of the history of the western United States the past 150 years has been the development of water infrastructure to match the expansion of irrigated agriculture, development of large urban centers, and the specific needs of key industries. The early-to-mid twentieth century saw the development of large-scale water resource facilities to meet growing water demands, particularly in urban areas. The development of reclamation projects throughout the west brought new lands into irrigation, including California's Central Valley Project.

Water Development

Water resources development has gone through significant changes in California over the past 150 years. Initial water projects were constructed by landowners or small communities to meet their needs: irrigation, gold mining and drinking water. As population increased in larger centers such as Los Angeles and San Francisco, larger projects were developed to bring domestic water supplies from hundreds of miles away. These large projects early in the twentieth century were largely single purpose: to meet the needs of growing communities. Several decades later saw the development of multipurpose projects, largely for urban and agricultural water supplies but incorporating hydropower generation, recreation, flood control and fishery benefits.

The projects shown in Figure 1, transferring water from east to west and north to south, were essential in the development of California's economy and large urban areas. But these projects also raised new concerns. California and much of the United States went through an environmental awakening beginning in the 1960s, resulting in a new "water ethic" and passage of many federal and state laws providing a greater level of environmental protection as it related to water projects. The next major change came about as the result of a prolonged drought in California from 1987 through 1994.

Much of California's developed water supplies are withdrawn from the Sacramento-San Joaquin Delta, a tidal estuary east of San Francisco Bay at the confluence of the Sacramento and San Joaquin rivers. The Delta is depicted in Figure 2 below. The drought seriously affected water supplies and the fisheries associated with the Delta. One of the consequences was greatly reduced water supply reliability to protect endangered fish species. Another was the development of market-based water transfers in response to the drought-induced statewide water supply crisis. Ultimately the drought and its impacts resulted in a high level of institutional attention and focus by federal and state water and environmental agencies. Various programs have been developed over the years, including the collaborative CALFED Bay-Delta Program. The successor effort is the state's Delta Stewardship Council. Such programs are attempting to address the water supply, quality, flood control and ecosystem problems of the Delta on a more comprehensive basis.

Figure 1. California's Developed Water Systems

Figure 2. Sacramento-San Joaquin Delta

Increasing Pressures on Water Supplies.

There have been a number of factors that contributed to greater attention to long-term water supply reliability over the past twenty years. Drought response and the increasing use of market-based water transfers played a major role, particularly because the need to meet dry-year urban water demands had a direct impact on irrigation water supplies. During drought conditions it is a “zero sum game”, with compensation provided to farmers and irrigation districts from urban water agencies seeking emergency supplies. There were other contributing factors. Many of California’s resource problems – air quality, water supply and quality, urban encroachment onto undeveloped and/or agricultural lands – are linked to population growth. Yet until recent years there were no explicit, comprehensive requirements linking water supply reliability to growth. In 2001 several new laws were passed to address this issue. The effect has been to require all proposed new subdivisions greater than 500 units (or an equivalent increase in water use resulting from industrial development) to develop a “water supply assessment” to assure that there are adequate water supplies to meet the proposed new water demands through at least the next twenty years. While this is substantially less than the 100-year standard used in Arizona, it was a start. Finally, for a variety of economic reasons, there is a high value placed on urban water supply reliability.

Research

In 1994 the California Urban Water Agencies (CUWA) undertook a study at the end of a serious statewide drought, “The Value of Water Supply Reliability: Results of a Contingent Valuation Survey of Residential Customers”. Conclusions at that time were: (1) on average, urban customers were willing to pay an additional \$12 to \$17 per month per household to avoid shortages similar to what had just occurred in the 1987-1992 drought; (2) this additional charge would amount on a statewide basis to over \$1 billion per year. This was a very large addition to typical urban water bills in 1994, although the study did not report that information. The California-Nevada Section of the American Water Works Association has in recent years done statewide surveys of urban water bills, but no information is readily available for the mid-1990s. A 1994 report by the California Department of Water Resources (DWR), “Bulletin 166-4, Urban Water Use in California”, has a chapter on urban water rates, but unfortunately that information is shown in terms of cost per acre-foot. Indications are, however, that urban water rates throughout California in the mid-1990s were in the range of \$10 to \$20 per household per month. Therefore, the willingness to pay extra to avoid drought-level water shortages approximates a doubling of urban water bills at that time. A separate study conducted by researchers at U.C. Davis about ten years ago, while critical of the methodology used in the CUWA study, did conclude that the economic costs of drought-level shortages in the future were at least as large as the willingness-to-pay numbers from the CUWA study, with roughly the same cost basis (1994 dollars vs. 1995). (Economic Losses for Urban Water Scarcity in California, Jenkins, Lund and Howitt, 2000.) That study also noted the lack of good field data to confirm estimates of economic costs. These studies reinforced the view that water shortages came at a substantial cost, and that ratepayers were willing to pay to improve water supply reliability.

Where We Are Now

The drought of the early 1990s coincided with imposition of increasingly stringent water diversion restrictions pursuant to the federal and state Endangered Species Acts. The increasingly troubled fate of key endangered fish species have brought about even more severe regulatory restrictions for both urban and agricultural water users who rely on water diverted from the Sacramento-San Joaquin Delta. Many have characterized such impacts as being akin to a “regulatory drought”, since the level of impacts on water deliveries are similar to a hydrologic drought.

In the agricultural sector, water supply reliability ranges widely throughout California. Most irrigation districts in the Sacramento Valley, and irrigation districts in operation before the 1950s in the San Joaquin Valley have very reliable water supplies. Their supplies are largely founded in strong appropriative water rights; some pre-dating the State’s permit system that came into effect in 1914. Similar legacy water rights support a high degree of water supply reliability for irrigation in the Imperial Valley in southern California. But other farming regions, particularly in the western and southern San Joaquin Valley, have increasing challenges to water supply reliability brought about by regulatory restrictions affecting imported surface water and an increasing concern about groundwater overdraft. While overdraft in the San Joaquin Valley is well documented, the matter of increasing regulatory restrictions on surface water imports and their impacts on agricultural water supply reliability are less well known by the public. Among the most significant restrictions are the reallocation of major amounts of agricultural water supplies to environmental purposes brought about by the 1994 Central Valley Project Improvement Act. That reallocation, coupled with increasingly restrictive federal Central Valley Project (CVP) pumping from the Sacramento-San Joaquin Delta, have decreased CVP supply reliability to farmers on the west side of the San Joaquin Valley from more than ninety percent to less than sixty percent.

WHAT DO WE MEAN BY RELIABILITY, SUSTAINABILITY?

There is an emerging focus over the past decade in California on both water supply reliability and the broader theme of “sustainability”. The common view of sustainability in recent debates is the ability to meet water supply needs well into the future even under uncertain conditions.

Water Reliability

A quick Google web search for “water supply reliability” yielded more than six million results. What are some of these links?

- Efforts to improve dry year water supplies
- Legislation addressing serious long-term drought (particularly Australia)
- Many “water supply reliability” studies
- Linkages between supply reliability and potential impacts from climate change
- The importance, value and costs of reliable water supplies
- Development of more sophisticated tools to evaluate supply reliability

- Re-evaluations of our current supplies and how reliable they may be (with special attention to the Colorado River, Sacramento-San Joaquin Delta, etc.)
- Water bond measures that include "water supply reliability" in the title, without defining what that means
- Linkages between water quality and water supply reliability
- The inevitable long list of academic studies and policy papers

While there may not be unifying definitions for water supply reliability and sustainability, there is broad recognition of the contributing factors. Those include, but are not limited to:

- Surface water hydrology (variability)
- Water infrastructure, for both storage and regulation of raw water supplies, and those facilities needed for treatment and distribution
- Water demands (variability)
- Interaction between surface water and ground water
- Regulatory restrictions

Each of these factors can be complex, as addressed in the following paragraphs.

<u>Surface Water Hydrology</u>. Hydrology by its nature is variable. Surface and ground water storage helps to buffer that variability. Our historical growth patterns, both in development of urban centers and our irrigated lands, have been based on the hydrologic variability as we understood it at the time we began that development, supplemented by storage investments. But we continue to see extreme events at both ends; this is broadening our understanding of variability and requires a new evaluation of reliability of existing water systems.

<u>Water Infrastructure</u>. Our water storage, diversion, distribution and treatment systems are integral to our ability to meet water needs from year to year and decade to decade. But they do require attention to "OM&R" – the costs for operation, maintenance and eventual replacement. We have been fortunate that California's large legacy water systems have been able to respond to new water management challenges that had not been foreseen when those projects were built. We have come to understand that our water infrastructure needs to be resilient, and that continued investments are needed to continue to meet needs. Today's population and extensive irrigated lands could not be served without our extensive, interconnected infrastructure.

<u>Water Demands</u>. In the 1960s most people could not imagine that we could make the widespread investments in improving water use efficiency that we have achieved in the past decade. We are getting more economic benefit from an acre-foot of water than we ever had, both in agriculture and in cities. We were forced to do this through a combination of economics and regulation. Improved water efficiency has been essential to maintaining water reliability and economic output.

<u>Interaction Between Surface and Ground Water</u>. We have greatly increased our understanding of the relationships between surface and ground water. While we are the only western state that has no uniform regulation of groundwater, we have greatly

expanded our understanding of the resource. Following several decades of failed efforts to bring about statewide regulation, State policy now encourages local stewardship of this resource. We have "groundwater management plans", "integrated regional water management plans", and in some cases local ordinances that regulate the increased use of groundwater pumping to support a transfer of surface water to another region. But while we can say in the short term that water supplies appear to be reliable (the water still comes out of the well on a regular basis), we cannot make the conclusion that such supplies are sustainable without addressing the recharge of our aquifers from surface water sources (natural or artificial).

Regulatory Restrictions. The extraordinary impacts from regulatory actions at times rival the impacts of hydrology on water supply reliability. Some regulations may have predictable impacts on reliability. These may include new water intake facilities to screen out fish, requirements for more efficient water appliances, and on-farm tail water recovery systems. But other restrictions such as those imposed under the state and federal Endangered Species Acts, respond to real-time data on fish and wildlife populations. Those impacts are very difficult to forecast and make it more difficult to plan for the future.

Water Sustainability

What about sustainability? This term is seeing increasing use in our society, in particular with regard to resource management: sustainable forests, sustainable water supplies, sustainable food supplies, etc. What do we really mean? In 1999 the Pacific Institute, an environmentally oriented "think tank" in the San Francisco Bay Area that has often taken on controversial water issues, collaborated with a number of foundations, federal agencies and urban water utilities to produce the report, "Sustainable Use of Water, California Success Stories." This report showcases 28 examples of urban, agricultural and environmental water programs. The overall thrust of these examples is to showcase "success stories … where efficient, equitable, and sustainable water uses are the norm, rather than the dream." While "equitable" and "sustainable" are not clearly defined, it is clear that the authors were writing about water projects and programs that were consistent or not in conflict with environmental goals. Examples include greater use of recycled water for urban and agricultural use, increased use of drip irrigation and crop shifting, other investments in urban and agricultural water use efficiency, and other actions to improve environmental resources through cooperative programs with irrigated agriculture. "Sustainable" in the context of this report does not appear to be defined as an absolute term. Rather, it appears to be a means to reduce conflict between human and environmental water uses.

EXAMPLES, INITIATIVES, CURRENT DIRECTION

California State Water Project, Reliability

Recognizing that there is not necessarily a unified definition of water supply reliability, what could it look like? For many years the author worked for DWR at both staff and leadership positions. DWR operates the State Water Project (SWP), a statewide water storage and delivery system that serves a population of more than twenty five million people and almost one million acres of irrigated farmland. In the mid-1980s DWR developed the concept of a delivery reliability curve, recognizing that the SWP was not able to meet its initial expectations of full contract amounts in all but prolonged drought years. Over time the concept of a delivery reliability curve expanded into a lengthy report issued every two years, providing updated information on all factors that have affected water delivery reliability. These factors have included increasing environmental restrictions, harsher droughts, and potential impacts of climate change.

The most recent delivery reliability curve is reproduced below.

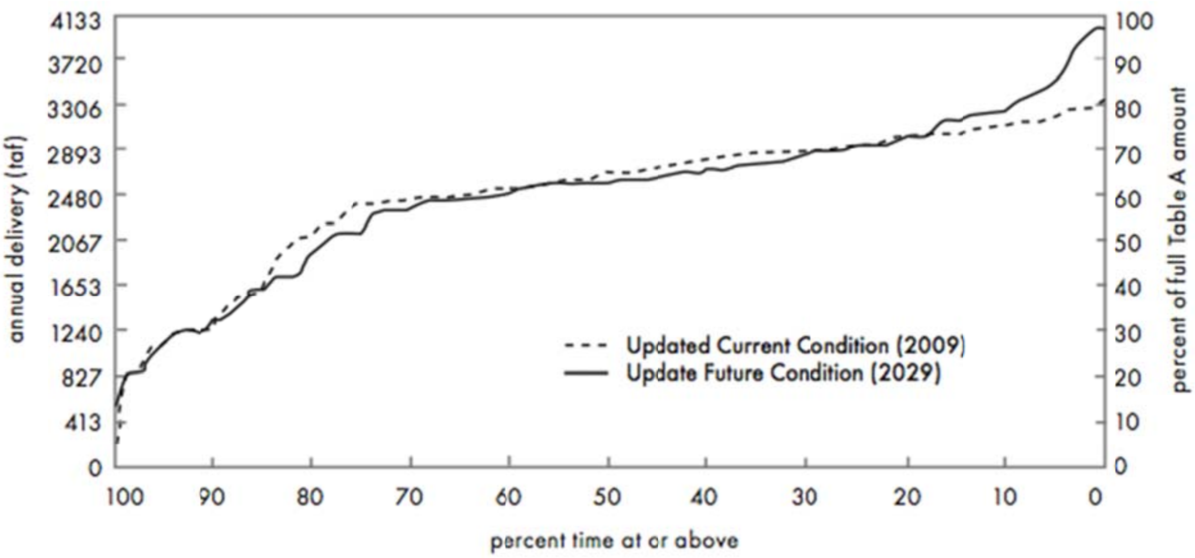

Figure 3. State Water Project Delivery Reliability

Figure 3 is from DWR's August 2010 report, "The State Water Project Delivery Reliability Report, 2009". The figure shows clearly what water users can expect from the State Water Project based on current facilities, regulatory restrictions, the variability of hydrology and anticipated changes over the next twenty years. These changes include assumptions for water demands in both the water source and water delivery regions, as well as conservative assumptions regarding potential impacts from climate change.

This biennial report is a thorough technical and policy analysis of the SWP's ability to deliver water, recognizing that few water users rely on the SWP as their sole source of supply. Even so, the delivery of water from this large statewide water project is an essential component affecting California's economy. This report is widely distributed to water utilities, land use planners and elected officials.

The Delta Stewardship Council, Defining Water Reliability

The broad California water community was fully engaged in the issue of water supply reliability with the Delta Stewardship Council throughout 2011. A very instructive letter on this topic was sent to the Council in March 2011 from the State and Federal Contractors Water Agency, a coalition of water users from both the federal Central

Valley Project and the California State Water Project that receive water diverted out of the Delta. That letter addresses differences between “system reliability” (physical availability and resiliency of storage, conveyance, and treatment systems that deliver water) and “supply reliability” (measure of the percentage of time full water demands or needs are met).

One environmental group suggested this definition: “Water supply reliability means feasible levels of certainty in providing water for reasonable and beneficial consumptive and non-consumptive uses, using a combination of water supply and water use efficiency.” It includes provisions for reasonable reductions in use in times of drought or other periodic shortages. It also recognizes that differing types of uses should have appropriate levels of water quality and differing levels of certainty. (Planning and Conservation League, April 29, 2011, provided to Delta Stewardship Council).

Note that this suggested definition includes a number of subjective, undefined terms and phrases: “feasible”, “reasonable”, “appropriate “and “differing levels of certainty”. While the agenda of this and other environmental groups is fairly clear in pushing a very strong level of water conservation in lieu of development of additional water supplies, the definition is useful and instructive. It recognizes that different types of water use could have different levels of reliability. It recognizes water quality as a component of reliability. In many respects it echoes the comments put forth by the State and Federal Contractors Water Agency. The Planning and Conservation League definition also recognizes the nearly universal view (reflected in law in many states) that water uses be “reasonable and beneficial”, and that there are consumptive and non-consumptive uses.

The most troubling component in this definition is “feasible levels of certainty”, which to environmental groups may mean the tradeoffs with environmental resources, and to water utilities may simply be cost-effectiveness (although the two are interrelated). As the Delta Stewardship Council wrestles with defining water supply reliability and putting a long-term framework in place, a challenge will be to understand the policy consequences of any definition.

A wide variety of suggested definitions were submitted to the Delta Stewardship Council over several months, and various sequential drafts of the Council’s Delta Plan attempted to address reliability in increasing detail. At the time the final version of this paper was prepared, the Delta Stewardship Council had released its fifth draft version of a Delta Plan (Delta Stewardship Council, Fifth State Draft Delta Plan, August 2, 2011), the first complete version of the plan to address the co-equal goals of water supply reliability and a healthy Delta ecosystem. Water supply reliability recommendations are a combination of investing in the health of the Delta’s ecosystem, and measures to be taken by water users to reduce their reliance on water diverted from the Delta. This draft Delta Plan calls for all urban and agricultural water users to prepare a “water supply element” in all of their water planning documents. This fifth draft of the Delta Plan does not specifically define or address water supply sustainability, although the thrust of the draft plan is that measures to improve reliability of supplies along with investments in the ecosystem will lead us in the direction of long-term sustainability.

The Challenge of Defining Water Sustainability

The modern concept of sustainability seems to have had its origin in the outcomes of the United Nations' World Commission on Environment and Development (WCED), often referred to as the Brundtland Commission named after the Commission's chair. WCED was convened in 1983 to address concerns " . . . about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." (United Nations, Report of the World Commission on Environment and Development: Our Common Future, 1987). The WCED report developed this definition: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

To that point, here is what the community internet resource, Wikipedia, says on this subject:

> *A universally accepted definition of sustainability is elusive because it is expected to achieve many things. On the one hand it needs to be factual and scientific, a clear statement of a specific "destination". The simple definition "sustainability is improving the quality of human life while living within the carrying capacity of supporting eco-systems", though vague, conveys the idea of sustainability having quantifiable limits. But sustainability is also a call to action, a task in progress or "journey" and therefore a political process, so some definitions set out common goals and values. (http://en.wikipedia.org/wiki/Sustainability)*

A common, thread, then, is to determine goals and indicators of sustainability as a means of improving the management of a resource – in our case, water. It appears to embody very long term goals, improvements in overall water use efficiency, reduced conflict with natural resources, and in some cases a political or policy agenda.

Is there a definition we can put to use in the context of public dialogues about sustainable water supplies? The Sustainable Water Resources Roundtable (SWRR), " . . . is a national forum to share information and promote indicators and research for sustaining water and related resources. It is an authorized working group of the Federal Advisory Committee on Water Information." The vision of the SWRR as outlined on its web site (http://acwi.gov/swrr/) is " . . . a future in which our nation's water resources support the integrity of economic, social, and ecological systems and enhance the capacity of these systems to benefit people and nature."

In 2009 Governor Brewer of Arizona created that state's Blue Ribbon Panel on Water Sustainability. The panel was formed following the Governor's commitment to collaboration on water resource issues, and in its first year put a great deal of attention towards developing clear terminology regarding the goals of sustainable water supplies. More information is on their web site, http://www.azwater.gov/AzDWR/waterManagement/BlueRibbonPanel.htm. The focus of the Panel appeared to be on investments in increased water conservation and recycling (reuse) to improve the long-term sustainability of Arizona's water supplies. The final report, dated November 30, 2010, does not define either "water supply reliability" or "sustainability", but aims to increase the reliability of current supplies through specific goals.

There are many complicating factors related to sustainable water supplies. In personal correspondence with Peter Binney, P.E., Director of Sustainable Infrastructure with Merrick & Company, Mr. Binney says:

> *The real challenge is in translating that in to a decision and planning, design process that actually minimizes and manages the balancing since it is not possible to achieve optimal performance for all parameters. We do not usually do a good job of considering the balance of qualitative and quantitative goals because the values are different and very personal in many water cases.*

Mr. Binney goes on to address some of the real-world issues associated with urban water supply sustainability:

> *We may not be able to be as absolute with the degree of impact minimization and regulation if we are to meet the goal of affordable water services (and remember that water is often seen as a right versus a commodity so balancing will not typically capture the real costs in order to achieve a political settlement).*
>
> *We are slowly developing our understanding of sustainability for a public good such as water services and these concepts will have to mature significantly if we are to get a full balancing of the costs of service with customer and political preferences.*

Next Steps, Indicators of Sustainability

Another approach to sustainability is to develop specific indicators. In the fall of 2010, the California Department of Water Resources began an effort to develop indicators of water supply sustainability as part of its period update to the California Water Plan. The specific question guiding this research is: "How can we ascertain that the resource management strategies and objectives of the California Water Plan are providing sustainable water uses and reliable supplies for the State and its various hydrologic regions?" One of the guiding principles DWR developed for the prior (2009) Update was to "determine values for economic, environmental, and social, benefits, costs, and tradeoffs to base investment decisions on sustainability indicators." A DWR staff presentation to the California Water Plan Advisory Committee on March 30, 2011 noted that there were no consistent terminologies and definitions of sustainability and its indicators, there was no systematic analytic framework or methods for quantifying indicators, and that in any event there was limited data. This presentation addressed the conceptual work plan to be undertaken to develop sustainability indicators, although the term "sustainability" was never clearly defined. In some sense, the indicators were a measure of the old adage, "we will know it when we see it." A relevant observation from Peter Binney (op cit) is to " . . . add objectives such as reliability, resilience, affordability, flexibility, achievability, adaptability to a sustainability assessment."

DWR's two-year work plan recognizes: (1) there are no consistent definitions of water supply sustainability, or even terminology to describe its components; (2) there is no "systematic analytical framework or methods for quantifying indicators"; and (3) there is limited, readily-available data to support an analytical evaluation. In a state with a population of thirty-eight million and more than nine million acres of irrigated farmland, the addressing of long-term water supply reliability and the sustainability of our water resources should be a high priority. While forecasts are for irrigated acreage to remain about the same or see slight reductions, California's population is forecasted to rise above fifty million in the next decade, and to almost sixty million by 2050 (2007, California Department of Finance). And yet no one assumes that we will see major increases in our developed water supplies.

OBSERVATIONS AND CONCLUSIONS: WHY WE CARE

Ultimately these subjects – water supply reliability and long-term sustainability – are topics we need to care about. And many water decision makers do care. All regions in California, both the highly urbanized coastal areas and the inland agricultural centers, have made major investments in water use efficiency largely for long-term sustainability – even though they may not have characterized it in that way. Farmers are shifting to high-value crops that require long-term investments in highly efficient irrigation systems, and they expect a long-term payoff. Cities continue to invest in water conservation, water recycling, water distribution system improvements, and other measures so that they can continue to grow and meet their long-term water needs without big increases in raw water supplies. Both water user categories have seen major upheavals in the reliability of their currently developed water supplies, and they are investing in part as insurance against future instability – whether it comes from water supply variability, the overall economy or other factors.

There is value in talking more specifically about sustainability. The danger is accommodating the agendas of one interest group or another, whether it is an environmental group opposed to growth or a developer with the opposite agenda. We do need the general public to understand that investments will continue to be needed to "sustain" our way of life, and also to understand the validity of issues raised by all interest groups and their consequences. Consumers are used to a full range of fresh vegetables at the grocery store. We want to restore incomes and jobs ravaged by the unstable economy. We need to catch up to the long list of deferred infrastructure investments. But there is a growing understanding that the general public does not understand how these pieces fit together.

A fundamental purpose of government is to plan for and make investments across multiple generations. It is not a leap to conclude that sustainability is a central role of government, supported by decisions of its citizens and community leaders. A combination of current and emerging events, including recent droughts, regulatory restrictions and the new charge for the Delta Stewardship Council, is expected to bring forward a broad public dialogue regarding California's long-term water supplies.

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MODERNIZATION PROCESSES FOR AN IRRIGATION DISTRICT — THE CASE OF SAN LUIS CANAL COMPANY

Alejandro Paolini[1]

ABSTRACT

The San Luis Canal Company (SLCC) has been working in conjunction with the Irrigation Training and Research Center (ITRC) on the modernization of the canal company's facilities since 2004. SLCC is located in the Central Valley of California and diverts its water from the San Joaquin River at Sack Dam.

The modernization of the facilities have included considerable discussions with the company's board members, canal ditch riders, company's maintenance personnel, a consultant engineering firm and outside contractors. After some rapid appraisals were conducted the company, installed a new Supervisory Control And Data Acquisition SCADA system, built a new central regulating reservoir, provided very good water level control at different key structures, installed flow control structures and remote monitoring sites of flows in and out of the company's service area. All these changes intend to simplify the water delivery operation for operators and managers, provide more flexibility for the farmers, reduce the districts spills, and decrease the pumping costs. This paper will provide the basic strategies and guidelines for this ongoing modernization process.

INTRODUCTION

San Luis Canal Company obtains its water supply through an Exchange Contract with the United States Bureau of Reclamation (USBR). The Exchange Contract allows the Company to receive its water through the Delta-Mendota Canal. Henry Miller Reclamation District No. 2131 (HMRD) was formed in year 2000. It works in conjunction with SLCC to deliver the irrigation water and provide drainage to the company's costumers. There are eighty six water users in the service area. The vast majority of the delivery facilities is now either owned by HMRD or has a permanent easement. HMRD is in charge of operating and maintaining the canals and drains.

As a member of the San Joaquin River Exchange Contractors, SLCC has an annual right of 163,600 AF in a "normal" year, and 123,000 AF during critical years. The actual deliveries to farmers average 139,000 AF per year. HMRD also "wheels" water to U.S. Fish and Wildlife, California Fish & Game, and to Grasslands Water and Resource Conservation District.

The system is completely gravity canals, with some recirculation pumps. It is comprised of a very old network of unlined canals and drains that were laid out on the contour over 100 years ago. Figure 1 shows how complex the layout of the system is. The gravity

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system is complemented with forty two deep wells and thirty three low-lift pumping stations to provide a level of flexibility at the cost of high pumping costs, water quality issues, high volumes of water lost to operational canal spills and twenty four hour calls in advance to order water and to shut the turnouts off. Most of the check structures were flashboards before the modernization began.

The district has about fifty nine miles of main canals, and ninety eight miles of lateral canals. Flow measurement to individual turnouts is measured with canal metergates. There are 1089 turnouts. In addition the district has 114 miles of surface drain ditches to maintain.

SLCC receives it water from the San Joaquin River into its main canal, the Arroyo Canal, which is seventeen miles long. This canal supplies five lateral canal systems located on the contour. Figure 1 shows the layout of the district. The different canal colors show the separate canal systems (Figure 1). All surface drainage flows that exit the district go back to the San Joaquin River.

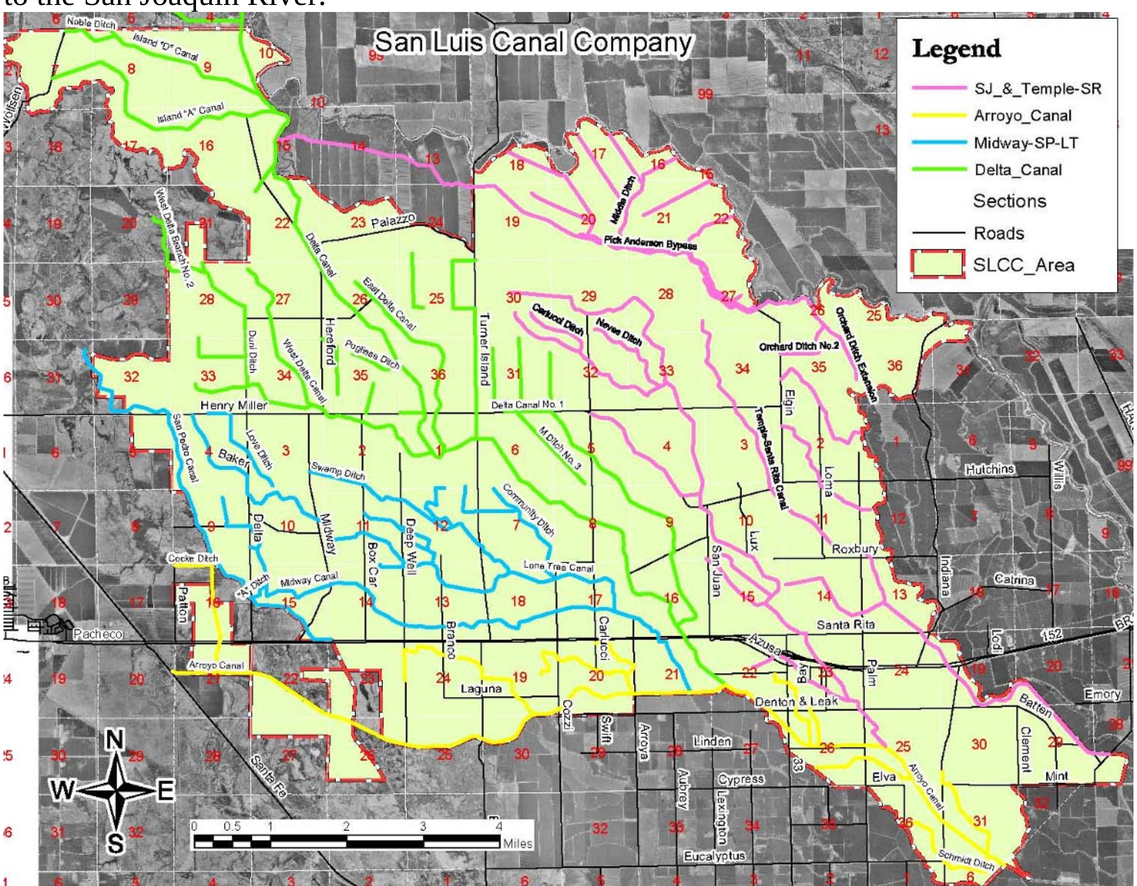

Figure 1. District Layout.

In 2004 the SLCC contacted the Irrigation Training and Research Center (ITRC) at Cal Poly San Luis Obispo to conduct a rapid appraisal process (RAP) from which the first ideas and strategies were set to start a modernization process to improve the flexibility. This first RAP set the bases for an ongoing modernization process that will be explained in this paper.

Figure 2. Typical District Structures:
a) San Joaquin River at Sack Dam, b) Temple Santa Rita backup Weir, c) Typical furrow irrigated field, d) Boundary Drain, e) Salt Slough Drain at Sand Dam.

THE PROCESS

The first RAP, provided a series of objectives:

First, a conceptual operations plan needed to be developed that resulted in most of the flow rate fluctuations being re-regulated. This will involve having water available “on demand” without needing to wait twelve to forty eight hours before making flow rate changes at the heads of those canals.

Many check structures needed to be converted to long crested weirs (LCWs) and ITRC Flap gates to maintain tight control of water levels regardless of flow rate changes.

New interceptor canals need to be installed of to pick up drainage water and excess water from canals at designated spill or re-regulation points.

Other objective was to construct regulating reservoirs at key points and computerization of control at key sites like at the inlets and outlets of the reservoir and at flow control structures.

This all combined with the installation of a SCADA system to allow an "Operations Supervisor" and the ditchtenders to know what is happening at key points throughout the system.

During the first few months after the first RAP, SLCC implemented some of the recommendations. Basically, SLCC started installing flow measurement devices and gathering water quality information throughout the district. Also a Global Positioning System (GPS) equipment was purchased and surveys were conducted to develop good topography and mapping data. Every check structure and canal heading was located and several key elevation information collected. Every turnout gate was located, gate type and size documented and field elevation data collected. All deep wells and low-lift pumping stations were located. Combining the GPS information and a Geographic Information System (GIS) maps were developed showing the location of all the important features so the information started to be organized for the Canal Company's service area. New printing equipment was necessary to appropriately present the new maps. A new color laser printer and a large color plotter were purchased with that intension.

Interviews with the canal operator were conducted to learn about the operations pool-by-pool and structure-by-structure on flow capacities and to know where problem structures were.

Information about well salinity capacities and costs was collected and organized on a monthly base. This helps develop an understanding on how much money is being spent on the company and private wells, the rules that govern their operation, and the salt load that is brought to the surface.

Graphs documenting how the water levels change with time combined with the surveying information about the level change across the adjacent turnouts was extrapolated to estimate how the flow rates to farmer’s fields vary with time unintentionally. This helped to build a case that everyone could understand. So the bases for the modernization process were set and a roadmap was delineated with the desired goals to achieve as follows:

- One person (the Operations Supervisor) observes flows at key points throughout the district, looking where there are excesses and deficits of flow. Decisions are made on an hourly basis as where flows into the heads of specific canals should be increased or decreased. This is a real-time and coordinated approach to the water distribution management throughout the district. This Operations Supervisor is responsible for seeing that each ditchtender has sufficient water available at the head of his canals. This task is performed either at the office on the SCADA system or from the ditchtender pickup truck from a mobile SCADA-attached computer.

- Several projects were identified and listed for improving the control of water throughout the whole service area by recognizing that the benefits of upgrades in one place will simplify the routing flows through other parts of the irrigation system.
- The recirculated water from most of the district is buffered in one centrally located reservoir. This buffer storage provides the operations supervisor an opportunity to calmly and effectively reassess the current supplies and deliveries, and the re-route flows in an appropriate manner.
- Drainage and canal spills from roughly seventy percent of the district are re-circulated at key points through a few specific drains.
- In the canals of the remaining thirty percent of the district, the supply is effectively located downstream—shifting from Mendota Pool to the heads of those small canals—placing a flexible supply very close to the farmer turnouts.

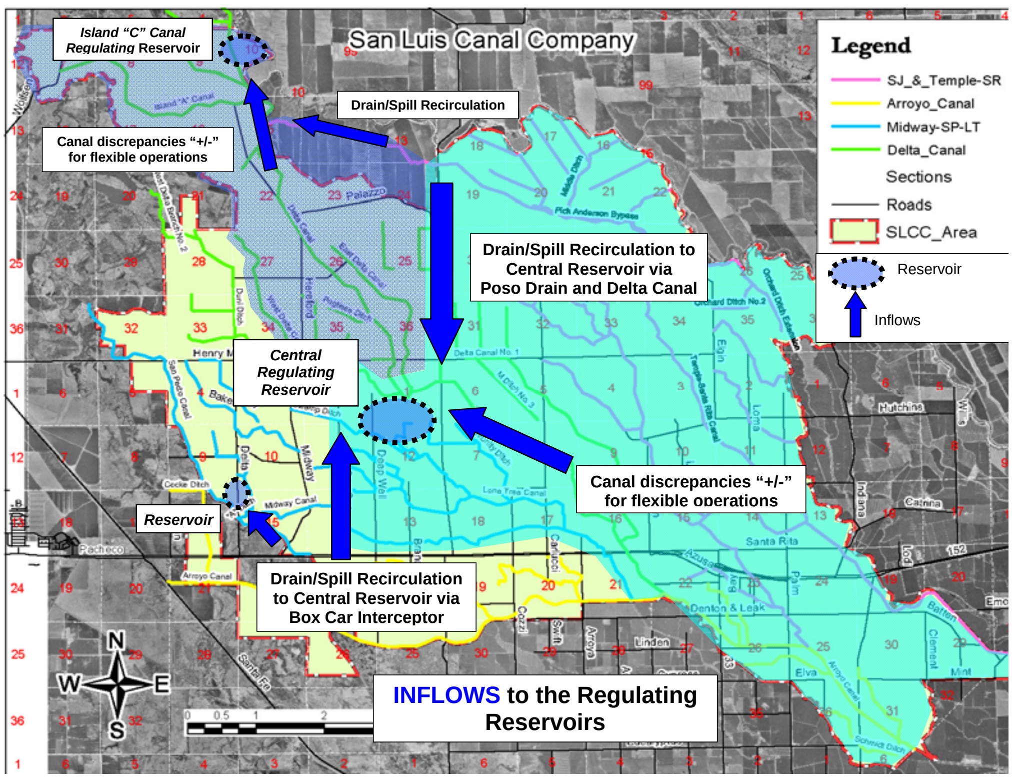

Figure 3. Conceptual layout for the INFLOWS to proposed reservoirs.

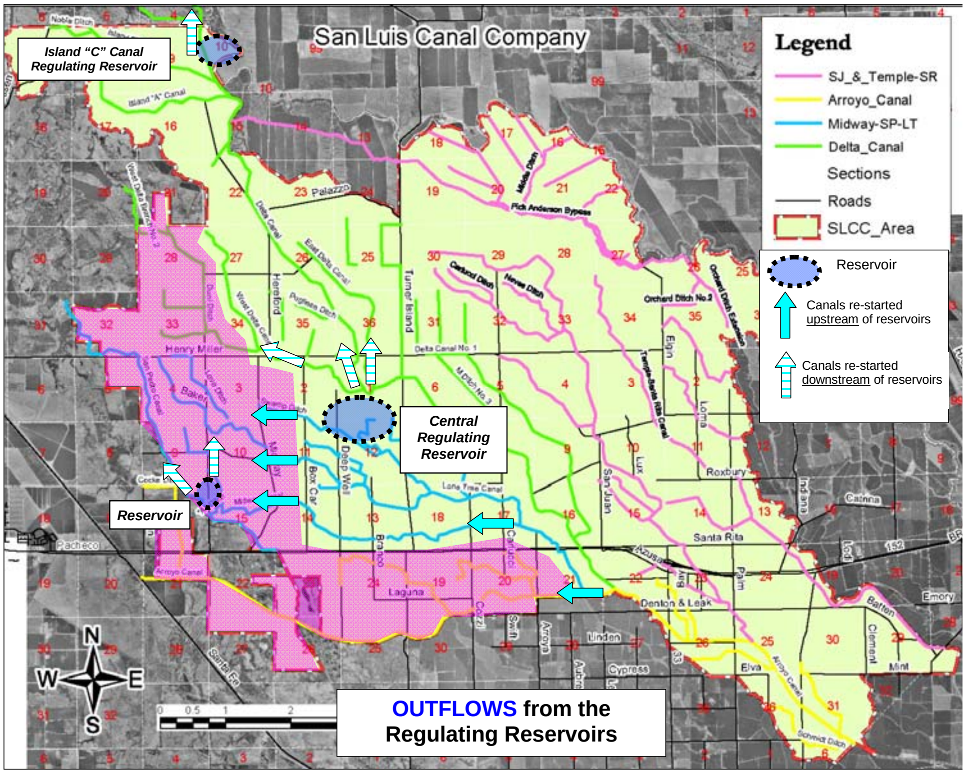

Figure 4. OUTFLOWS from the regulating reservoirs and re-locating the heads of upstream canals.

Figure 3 illustrates the conceptual layout of the INFLOWS into three proposed buffer reservoirs. Only the central regulating reservoir has been constructed so far.

Re-circulated water can be rerouted to the central reservoir from three sources: the Delta System, the Poso Drain System, and the Box Car Interceptor Drain System. The last two projects can be considered big picture projects in their own right because they impact large proportions of the service area and involve a number of subprojects with a sequence of construction activities. But both are reliant on having the central reservoir in place first.

Figure 4 illustrates the outflows from the regulating reservoirs which also allow the restarting of upstream canals with a controlled flow rate closer to the delivery turnouts.

Both Figures 3 and 4 are conceptual maps that demonstrate the big picture strategic concept. But many individual actions in different canals and drains are inter-related components in the overall modernization package that needed to be done jointly for the system to work as envisioned. The actual implementation of the new management strategies using the reservoir is a multi year process, therefore the modernization projects were separated into phases. Some short term actions for the first three years (2005–2008) focused on providing relevant justifications and design details. It was decided to do some things first that would provide significant advances to farmers and operators since building on the success of these initial modernization projects was a key strategy to getting endorsements for future projects and for seeking outside sources of funding. Since

2004, the district applied for grants to different programs from the USBR and received roughly $770,000 for the study, planning and mainly the implementation of the modernization process.

PROCESS PHASES

Phase 1 (Completed: 2004–2005)
Installation of flow monitoring site at the Head of the Arroyo Canal
$41,017

Phase 2 (Completed: 2005–2006)
Installation of flow monitoring site at Poso Slough (inlet)
$26,903
Installation of flow monitoring site at Wood Slough (inlet)
$30,308
Installation of flow monitoring site at Muller Weir (outlet)
$18,825

Phase 3 (Completed: 2006–2007)
Installation of LCWs and ITRC Flap gate on San Juan, Delta and Swamp
$77,413
Design of the reservoir, pumping stations and SCADA system
$95,000

Phase 4 (Completed: 2007–2008)
Installation of five LCWs on the Midway canal system
$109,281
Installation of one LCW and at the Pick Anderson North Bypass ditch
$40,099
"Automation" of the Pick Anderson No. 1 Pump for water level control
$12,215
Installation of flow monitoring site at San Juan Drain (inlet)
$30,500

Phase 5 (Completed: 2008–2009)
Land acquisition and Construction of the central reservoir
$1,616,487
Construct new flow control structure for the West Delta Canal
$152,604
Construct new flow control structure for the Delta Canal
$71,813
Installation of flow monitoring site in Salt Slough at Sand Dam (outlet)
$61,492
Installation of flow monitoring site in Boundary Drain Dam (outlet)
$92,237

Phase 6 (Completed: 2009–2010)

Installation of six LCWs and three ITRC Flap gate on the Delta canal system
$446,545

Construct new flow control structure on the Arroyo Canal at Junction Weir
$135,161

Install two new VFD-equipped pumping stations (Inlet-Outlet pumps)
$444,346

Installation of one LCW at Sand Dam
$137,320

Phase 7 (Completed: 2010–2011)

Installation of five LCWs and four ITRC Flap gates in the T.S.Rita system
$195,330

Installation of new SCADA system
$262,770

Installation of reservoir pumps flow meters
$84,760

Automation at the Head of the Arroyo Canal
$191,144

Phase 8 (In Progress: 2012)

Automatic water level control at Sack Dam
$255,000

Installation of a flow control structure on the Temple Santa Rita canal
$170,000

Construction of the Eastside Conveyance-Poso Drain Re-circulation System
$3,000,000

Installation of four LCWs in the Arroyo canal
$885,000

Phase 9 (Future)

Construction of the Box Car Interceptor Drain System
Connecting more monitoring sites into the SCADA system
New dam and fish screen at Sack Dam

SCADA SITES

The central reservoir is the essential feature that ties everything together and its implementation changed how the canal systems operated. First a SCADA Integration Team was defined consisting of SLCC, Sierra Controls an Integrator with experience in irrigation SCADA applications, Summers Engineering responsible for most civil works, an electrical engineer hired by SLCC, and the ITRC.

The Central Reservoir SCADA project includes five sites for automatic control with remote monitoring functions, and a base station at the district's headquarters office. The SCADA for the reservoir consist on the automated Inlet/Outlet, Delta flow control

Structure, West Delta canal Flow Control Structure, the Poso Drain Emergency Spill, and the Office Base Station. **Figure 6** shows a map with the layout and location of the sites.

The project encompasses automated Variable Frequency Drive (VFD)-equipped pump controls, automated control of canal sluice gates, electronic flow measurement devices, mobile interface terminals, and computer and communications support systems at the office with alarming, report generation, and data management capabilities.

The major components of the Central Reservoir SCADA system are the Remote Terminal Units (RTUs) containing the Programmable Logic Controllers (PLCs), the master base station at the office, radio communications equipment, and various field instruments and measurement devices.

The use of robust equipment and software conforming to standardized specifications, ensure the implementation of a properly engineered SCADA system that is reliable and prepared for future expansion.

The design of the new SCADA system was guided by the following overall requirements:

- Open system architecture
- A robust high-speed data radio network
- Industry standard hardware components
- System scalability
- High system reliability with redundancy of critical systems
- Configuration using off-the-shelf Windows-based software
- Distributed environment with automatic recovery and restart

Site 1: Central Reservoir Inlet/Outlet

The Central Reservoir is a 200 acre-foot reregulation reservoir in the middle of the district's irrigated service area. The reservoir is located at the division point of the Delta Canal and West Delta Canal as shown in **Figure 5**. A SCADA system was designed for controlling six (6×) automated pumps and three (3×) sluice gates at the Central Reservoir Inlet/Outlet. The RTU, motor control panels, VFD panels, etc. were installed in a control building (temperature controlled).

The conveyance capacity of the Delta Canal in the section adjacent to the reservoir is 150 cfs. The West Delta Canal has a conveyance capacity and design flow rate of 150 cfs.

The reservoir's active live storage capacity is 200 acre-feet to provide up to ±100 acre-feet of operational buffer storage depending on the present water elevation in the reservoir.

Based on the water level in the reservoir and system demands, gravity or pumped flow occurs in either direction. The maximum capacity of the pumps into the reservoir shall be 200 cfs (future) and the pumps out of the reservoir are 100 cfs.

A drawing of the new Inlet/Outlet facilities at the Central Reservoir is shown in **Figure 6**. The Inlet pumping plant consists of one (1×) 33cfs, 75-HP (input HP to the motors) pumps and two (2×) 36 cfs, 75-HP VFD pumps for the lift from the T-Pool. The Outlet pumping plant consists of one (1×) 33-cfs, 75-HP (into the motors) pump and two (2×) 36 cfs, 75-HP VFD pumps.

Four pumps at the plant are equipped with automated VFDs; the complete pumping station automation programmed by ITRC was connected to the SCADA system. Later, the district may add three (3×) 33 cfs inlet pumps. The automation programming was designed for the eventual build-out, which will occur as the complete SLCC system is being modernized.

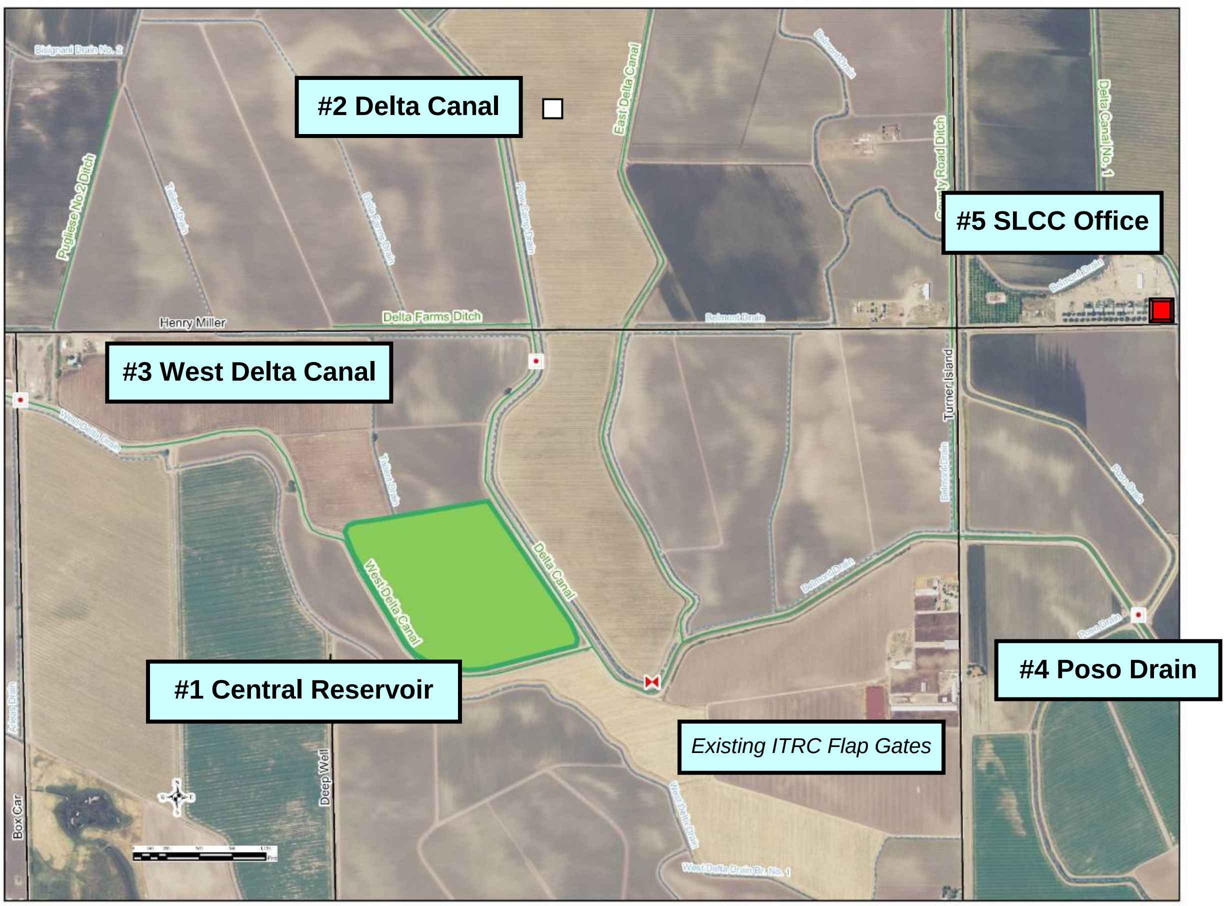

Figure 5. Location map of the SLCC Central Reservoir SCADA System

The PLC and other SCADA components were designed to accommodate flow meters (4-20 mA) for each pump.

The SCADA system at the Central Reservoir performs the following functions:

1. Automated control of a user-defined target elevation in the T-Pool
2. Remote manual operation of the Inlet and Outlet pumps
3. Remote manual control of the Inlet/Outlet gates to move to a target gate opening

4. Remote monitoring of system status (positions, alarms, pump status)
5. Remote monitoring of the water levels in the reservoir and canal pool
6. Remote monitoring of the canal flow rates
7. Remote monitoring of the temperature in the control building.

ITRC designed, modeled, troubleshoot, and supplied the control code, programmed in an automation software (ISaGRAF). The automated control of the reservoir inflows and outflows was based on maintaining a constant water level in the adjacent canal pool. Final control constants for the PLC calls for a change in pump speed or a change in gate opening corresponding to a desired change in flow rate. This requires PLC-based control using a special ITRC control algorithm for the pumps and reservoir gates.

An unlicensed spread spectrum radio network (902-928 MHz; FHSS) is the communications backbone for this system. Reliability of data transfer with a minimum of first time transmission failures is a high priority of the project. The antennas were installed on forty foot tall towers secured in a concrete footing.

SLCC constructed a control building at the reservoir site to secure the pump controls, RTU and linked electrical components. The control building is totally enclosed and temperature controlled by a conditioner/heater unit. All motor control panels, LCD panel, VFD controls, Hand-Off-Auto (HOA) switches, pushbuttons, PLC, fused terminal panels, flow meter displays, etc. were wall-mounted in NEMA 4 enclosures inside the building.

The entrance to the control building has a double door, vandalism resistant design with a steel plated outer door and locking hasp. An intrusion alarm connected to the PLC was installed to send an alarm signal to the base station HMI whenever the entrance door is opened. The control building has a work table and chairs for personnel to work inside with well lit conditions, with easy access to the system for laptops, testing equipment, and tools. Documentation binders are maintained on-site in designated holders.

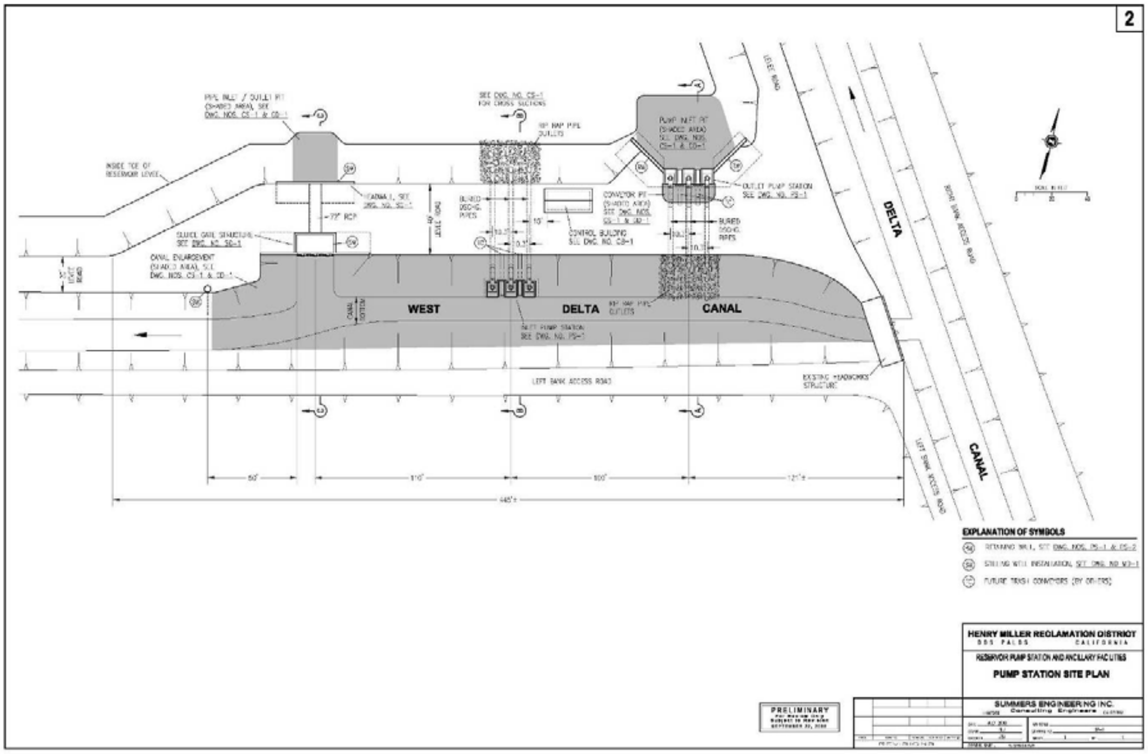

Figure 7. Site plan drawing of the Central Reservoir Inlet/Outlet facilities

The RTU requires redundant sensor systems for measuring all analog sensors values. Redundant sensor systems were provided for the following:

- Water elevation in the reservoir
- Water elevation in the canal pool
- Water elevation on the downstream side of the sluice gates
- Gate openings for 3× sluice gates

A total of 12× water level sensors are required according to the configuration shown in **Figure 9**. In each sensor pair, there is one sensor of a different type (e.g., pressure transmitter KPSI 730T pressure transmitter (±0.1% FS accuracy) or ultrasonic Siemens Sitrans Probe LU transmitter 4-20 mA). All water level sensors were installed inside separate stilling wells.

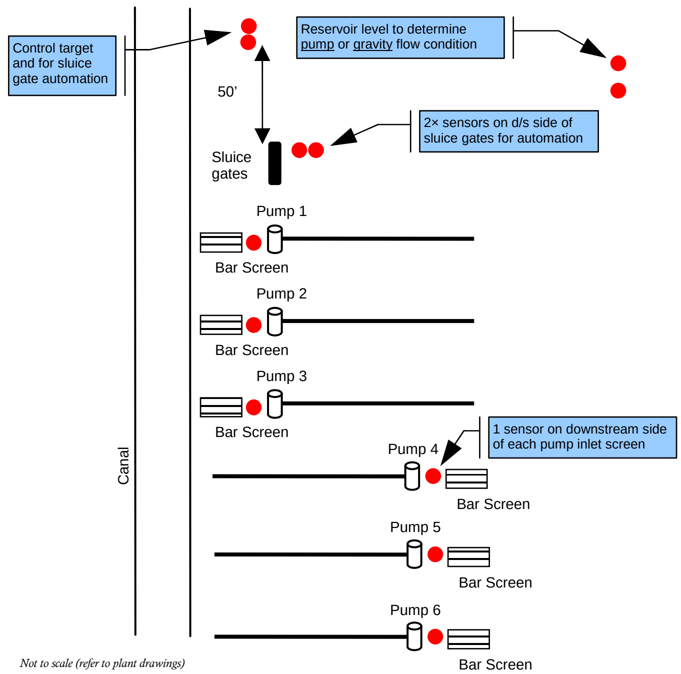

Figure 9. Configuration and layout of water level sensor at the Central Reservoir

Figure 10 shows a picture of the finished facilities at the central regulating reservoir.

Sites 2 & 3 Delta and West Delta Flow Control Structures

The Delta and West Delta Canals are medium-size irrigation canals that run along the eastern and southern boundaries of the Central Reservoir. (**Figure 6**)

Figure 11 shows the new flow control structures in the Delta Canal and West Delta Canals. The structures were retrofitted because in the new operational scheme with the reservoir, the Inlet/Outlet (pumped and gravity) maintain a constant water level in this pool by buffering ± flow discrepancies, and the Delta and West Delta canals “re-start” with a target flow rate based on downstream demands. The West Delta flow control structure is brand new. On the T-pool, water is available on demand, within limits, from the reservoir so canal operators can offer more delivery flexibility to growers.

Figure 10. SLCC Central Regulating Reservoir. View of the Control Building, Pumping Stations and Automatic Sluice Gates

The new structures operate as a flow control structures consisting of two metal sluice gates each with electric gear-driven actuators, and high/low limit switches. The actuator on each gate modulated by the PLC based on user-defined set points transmitted from the HMI. The control logic moves one gate per control time step for precise control.

The SCADA system at the Delta and West Delta Canals perform the following functions:

1. Automated control of a user-defined target flow rate
2. Remote manual control of the sluice gates to move to a target gate opening
3. Remote monitoring of system status (positions, alarms, gate status)
4. Remote monitoring of the water levels in the canal pools
5. Remote monitoring of the canal flow rates

The automated control of the sluice gates is based on maintaining a constant flow rate through the gates until a new target is entered into the system via the Human Machine Interface (HMI) or Operator Interface Terminal (OIT). Final control constants for the PLC call for a change in gate opening corresponding to a desired change in flow rate. This requires PLC-based control using a special ITRC control algorithm for the gates.

Figure 11. New flow control structures in the Delta (left) and West Delta Canals (right)

The district installed galvanized vandalism enclosures for the SCADA RTU at the Delta flow control structure (**Figure 11 left**) and built a new control building for the West Delta structure planning in the future Box Car re-circulation pumps (**Figure 11 right**).

The Delta and West Delta canals RTUs require redundant sensor systems for measuring all analog sensor values. Redundant sensor systems were installed for the following:

- Water elevation in the upstream canal pool
- Water elevation in the downstream canal pool
- Gate openings for 2× sluice gates

A SonTek Argonaut Side-Looking (SL) acoustic Doppler flow meter was installed. The flow meters have an RS-232 serial cable that is installed in conduit from the flow meter to the RTU. The installed flow meter system includes a Modbus interface to link the PLC and radio modem in the RTU.

Site 4: Poso Drain Emergency Spill Gate

For emergencies with a high water level alarm in the T-Pool, an emergency spill gate RTU and actuator were supplied by 24/48 VDC with a battery back-up system in the event of an AC power failure. The district installed a vandalism enclosure with a RTU adjacent to the gate with power connected at the existing pump station and utility service pole. A spread spectrum data radio modem was connected to the PLC and programmed transmits data to/from the office base station and the Central Reservoir. A Yagi directional antenna was installed.

Long Crested Weirs and ITRC Flap Gates

By using LCWs and ITRC Flap gates rather than normal flashboard weirs as a control structure, the water level variation over the crest was reduced by about 75%. (**Figures 12 and 13**). SLCC has successfully built twenty five LCWs of different sizes and installed nine ITRC Flap gates at various locations in the canal system.

These structures are not an automated structure, technically speaking. However, when properly designed and operated, the water level control can be equivalent to that achieved with some sophisticated automation techniques.

A significant reduction of the fluctuations of the water level in the canals was achieved that provided more constant water deliveries through the canal turnouts located upstream of the structures .

The better water level control and management practices improved the reliability and the flexibility of the water deliveries and promoted accurate measuring and accounting of irrigation water.

Good water measurement facilitates accurate and equitable distribution of water resulting in fewer problems and easier operation.

Figure 12. ITRC Flap gates TSR Canal Ext.

Figure 13. LCW Delta D/S HWY 152

CONCLUSIONS

SLCC started its modernization process by getting a Rapid Appraisal done, building a work team and basing decisions on a strategic plan that took a relatively long time to settle in all the participants minds. Sometimes was very difficult to keep everybody on the same page. After the first steps showed the benefits and the improvements then the projects became easier to implement and funds for construction were easier to get. Better understanding through a water and salt balance and on the proposed ideas was necessary. We learned many lessons throughout the design and implementation phases of the modernization projects. Luckily SLCC and HMRD board of directors has been very supportive to the modernization process especially after the implementation of the GIS

and the construction of the firsts LCWs. The farmers literally loved the new structures since they noticed their work in the field gets easier and more predictable.
Funds are the essence for the implementation of any kind of project. The funding support from the USBR has been crucial for the success of the modernization process.
The implementation of the SCADA system was a long and relatively expensive process but now that is implemented it is expanding rapidly on new applications making it a good investment. Our modern system is new and I am sure some problems will rise and new solutions will need to be found.
The success of this process is due to the directors and district manager's willingness to invest money to take some of the "art" of ditch tending away and to make the water delivery an industrial process.

ACKNOWLEDGEMENTS

I would like to give special recognition to several persons and institutions for their contribution to these projects. I would like to thank the general manager of HMRD, Chase Hurley for his support and leadership to turn this plan into a reality. I would like to extend our recognition to the Bureau of Reclamation for providing funding for the construction of several structures and implementation of the SCADA system. We also appreciate the cooperative spirit of the ITRC team from Cal Poly San Luis Obispo in the planning, the design and construction phases. The participation of Summers Engineering, Sierra Controls, Conco West Construction, and Phase 1 Construction for all their hard work under adverse field and weather situations.

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DRIP IRRIGATION SYSTEM COST SHARING BY IRRIGATION DISTRICTS FOR WATER CONSERVATION

Charles M. Burt, Ph.D., P.E.[1]

ABSTRACT

Government and irrigation district cost sharing programs have often included financial support for the installation of drip/micro irrigation systems. These programs seek advantages that might include improved crop yield, less applied water, and a reduction in subsurface drainage water and surface tailwater. They may also seek to reduce water consumption. The actual results have been shown to vary by district, hydrology, and crop.

It is true that drip systems in California, on average, have good Distribution Uniformities (DU) of irrigation water – meaning that there are only minor differences between the depths of water received by various plants throughout a field. However, irrigation district cost sharing programs could obtain even better results by requiring specific attributes and equipment in the drip/micro systems that receive financial assistance. Items such as properly placed flow meters, excellent filtration, new system DU, good fertigation systems, efficient pumps, and maximum allowable pressure requirements at the pump are all easy to specify, do not add significant cost, and will improve initial performance and later management options.

INTRODUCTION

Cost sharing programs exist because of perceived benefits. A cost shared item may be presented by different programs as achieving varied objectives. Programs that involve cost sharing with farmers have an additional feature in that they have two tests to pass:

1. Farmers must receive definitive benefits from their investment portions.
2. The district would like to receive benefits.

The goals of the two partners may be quite different. The farmer is interested in benefits and disadvantages as they relate to items such as:

1. Management time
2. Investment cost
3. Fuel expenses
4. Water bills
5. Labor
6. Yield
7. Crop quality
8. Maintenance
9. Net profit/loss

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Although in principle the irrigation district is interested in good outcomes that will directly help farmers, the district generally has more interest in various other objectives:

1. Reduced diversions
2. Reduced high water table problems that may cause regional drainage problems, or which might cause difficulties with drain water disposal due to poor water quality
3. Reduced surface drainage water recycling (that originated from tailwater), and less sediment from that surface water recycling
4. Ability to increase irrigated acreage
5. Checking off a box that some state regulator devised to demonstrate that the district is active in water conservation efforts
6. Reduced groundwater overdraft
7. Reduced irrigation water consumption

This paper addresses three fundamental questions:

1. Which of the farmer expectations, if any, are realistic?
2. Which of the irrigation district expectations, if any, are realistic?
3. How can optimal success of conversion to drip/micro systems (and, as a result, any cost-sharing program that promotes the conversion) be achieved?

ARE FARMER EXPECTATIONS REALISTIC?

In general, drip/micro irrigation has proven to be a very positive investment. This is clear, based on the continued expansion of drip/micro acreage. But it is also very true that there have been catastrophic failures that have generally been caused by farmers expecting extraordinary benefits from marginal investment in capital and time. Grant programs should be designed to help farmers succeed, and therefore it is important to understand what uncertainties exist, with a goal of then minimizing potential problems.

Uncertainties of drip/micro outcomes from the farmer perspective include:

1. The results obtained and the ease of management will depend upon the quality of equipment, the suitability of the design, and existence of certain useful features (which will be explained later). Saying that you have a drip system is like saying “I have a vehicle.” It does not reveal very much.

2. There are often unexpected fatal errors in design or management in the early stages of drip/micro in a region. Small details become major headaches. Problems can vary from unexpected iron bacteria problems to varmint nibbling damage, human vandalism, salinity buildup patterns, poor yields due to excess or deficit irrigation, or wasps that plug microsprayers. The list is expansive.

Figure 1. Unexpected leaks in a subsurface drip irrigation (SDI) installation on tomatoes.

Figure 2. Critter cage around valve – but the critters still got in.

3. The more crops that are involved, the more complicated it becomes to design and manage a drip/micro system. Alfalfa, lettuce, processing tomatoes, cotton, pistachios, almonds, table grapes, and wine grapes (as examples) all have unique design and management problems. However, after five to ten years on a specific crop in an area, with progressive farmers and good irrigation dealers who are willing to test and share new information, most of the lessons have been learned. After this break-in period, chances for success on a new field are much greater than for early innovators in an area.

   For example, in the San Joaquin Valley of California there are extensive drip/micro systems on crops such as citrus, almonds, pistachios, walnuts, and processing tomatoes. New drip/micro systems on these crops benefit from extensive design and management experience. Specifically, on almonds we know that double line drip or microsprayers are needed, but pistachios do not seem to need an increased wetted soil area. With processing tomatoes, not only is the drip system important, but using the correct tillage equipment is as well. The chance of success of new drip/micro systems greatly improves by building on earlier trial and error and lessons learned.

Figure 3. Almonds with double line drip (R) versus pistachios with single line drip (L). Major differences in wetted soil percentages. Note the two hose ends coming out of the ground on the almonds. An earlier SDI system was abandoned.

4. Some crops show major improvements in yield and quality; other crops do not. For example, some of the largest table grape and nectarine farmers in California firmly believe that fruit quality suffers if they use a drip/micro system. The response of many crops such as onions and lettuce will depend upon the crop variety. Cotton requires special care because of its sensitivity to both over-irrigation and under-irrigation, and the timing of both. With other crops such as processing tomatoes, peppers, broccoli, almonds, and varieties of onions, the yield increases have been remarkable when combined with proper fertilizer management. In the last ten years processing tomatoes have moved from about thirty-five tons per acre to double that; average almond yields are now at least double of what was obtained with surface irrigation. Drip on processing tomatoes is especially productive on poor and salty soils.

Figure 4. Cotton on drip that was over-irrigated and matured into miniature trees without many bolls.

5. Reduced management time is rare for the first season. In fact, the management time required for unexpected problems can be overwhelming for some farmers. Eventually, unless there are persistent problems (such as coyotes, gophers, etc.) the management time is reduced. What actually happens is that good drip/micro system inherently becomes “more manageable” than other irrigation systems, so the benefits per hour spent can be increased.

6. Reduced labor may or may not occur. If a system is poorly designed, or if there are problems with varmints, insects, or plugging, there can be very large labor requirements to maintain a drip/micro system. Some growers in California have abandoned drip systems because of the high maintenance and labor costs. It is also noteworthy that with over 40 years of drip behind us, the majority of excellent drip/micro systems are not automated – the logic is that people need to be in the field anyway.

7. Drip/micro systems will cost in the $1000 - $2500/acre range when all things are considered. Due to the large variability in design requirements for each individual field, costs vary significantly for farmers. But the quality (and therefore, the cost) of irrigation systems proposed by irrigation dealers is highly variable. Farmers have difficulties evaluating the merits of various bid proposals.

8. If a previous irrigation system was very inefficient, and if the new drip/micro system is very efficient, there can be substantial water cost savings if the annual applied irrigation water is a large number. However, that water cost savings is based on those two very big assumptions. In general in California, it is likely that the water applied on orchards and vineyards, especially on variable soil and in small fields, is greater with surface irrigation than with drip. On the other hand, if one examines processing tomatoes, the water volume applied on heavier textured soils during the irrigation season is very similar before (with surface irrigation) and after (with drip).

9. While there are always exceptions, energy consumption, on the average, increases with drip/micro systems. Many farmers convert to well water instead of surface water because of the flexibility and clean water associated with wells, and drip/micro systems are usually designed to need about 40-45 psi at the pump discharge on a flat field. When compared to an entirely gravity supply system on furrows, the energy requirement for pumping is substantially more with a drip/micro system.

ARE IRRIGATION DISTRICT EXPECTATIONS REALISTIC?

Terms such as "irrigation efficiency" and "water conservation" mean something different to almost everyone, regardless of various attempts to carefully define such terms. Furthermore, any program to improve something should first have an excellent notion of the present status.

"Water conservation" programs should ideally follow a 5-step process:

Step #1. *Create a clear definition of the goals*. For example, reduced water consumption may be a goal. Reduced water consumption will technically mean less evapotranspiration, often with the addition of less flow to salt sinks. This can be entirely different from applying less water to individual fields. In fact, it is well documented, and intuitive, that healthy, unstressed plants with uniform growth across a field will have a higher evapotranspiration (consumption) rate than fields less healthy plants, stress, and uneven growth.

Step #2. *Implement a scientific examination of the overall potential to reach the goal*. In most cases involving water conservation on an irrigation district level, this means that an excellent water balance must be developed to determine the sources and destinations of water. For example, if there are large amounts of re-circulation of return flows (surface and subsurface) within the district boundaries, there may be little opportunity to truly conserve water. Keep in mind that this discussion deals with irrigation district goals, not farmer goals (which include higher yields).

Step #3. *Closely examine what fraction of the potential conserved water, for example, will be addressed by increasing the acreage irrigated by a drip/micro system*.

Step #4. *Require certain options and performance standards for new drip/micro systems*. For example, requiring a flow meter for each system may seem obvious but it is not necessarily required in some programs. In fact, often very little is required.

Step #5. *Verify results*. Anticipated results may not meet achieved results, and unless installed performance is verified, it is difficult to know if objectives have been met. For example, this past summer the Irrigation Training and Research Center (ITRC) evaluated thirty-five fields in Westlands Water District that had new, grant-related irrigation systems. The fields were evaluated for both Distribution Uniformity and how well the irrigation scheduling matched evapotranspiration (ET) requirements. To illustrate historical variation, Figure 5 below shows approximately 15 years of results of drip/micro irrigation system evaluations using the standardized Cal Poly ITRC evaluation procedures.

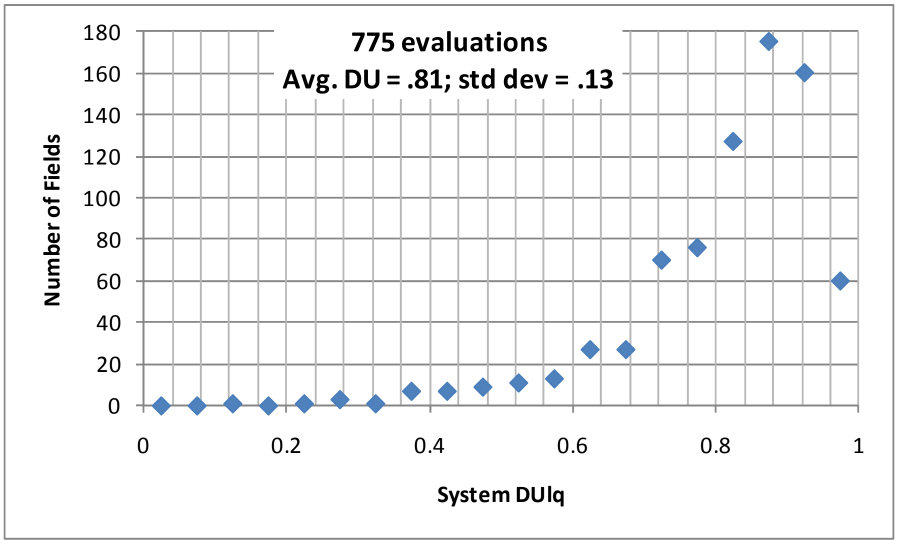

Figure 5. Drip/micro irrigation evaluation results from California

ESTIMATING REDUCED APPLICATION VOLUMES

The term "application" refers to the gross applied water, not the net. The word "reduced" infers that there will be a comparison between the "old" and "new" applications. There is no general rule in terms of a specific percentage. Instead, the following items should be noted:

1. There can be no valid estimate of application reduction unless one first has well documented historical applications on the same crops.
2. The historical applications should be compared against the net requirement (crop ET, plus leaching requirement, minus effective precipitation) to see what the magnitude of application reductions might even be. If the historical application is no more than twenty percent greater than the net requirement, there is likely little change of reduction.

Obviously there are always extreme cases, but they can be identified by following the two points listed above. Perhaps cost sharing programs should only target extreme cases. But in California, with crops such as processing tomatoes that are often grown on "heavy" textured soils in areas with limited water supply, ITRC has documented that typical average reductions in application are in the neighborhood of 10%. It must be emphasized that if the district program goal is to have major differences in application depth (without considering net reduction), this is important. There has been widespread acceptance and support of these programs by farmers, but their goals are different than district goals.

ENSURING EXCELLENT PERFORMANCE

USDA/NRCS has certain requirements for its cost sharing programs but those could be improved. Irrigation district cost sharing programs in California seem to have few requirements regarding specific performance measures or equipment, which means the programs are often relatively unregulated and the results can be questionable. The cost sharing programs typically just pay some percentage of the cost, up to some dollar maximum, of a new irrigation system - no questions asked except that it be placed on land within the irrigation district.

There is an existing tool that could be used as the first step in improving these programs. In 1994, the Cal Poly ITRC worked with various utilities and irrigation groups to develop the "Irrigation Consumer Bill of Rights" (ICBR), which was in fact two Bills: one covering general irrigation and the other dealing with drip/micro irrigation. These Bills, which include simple lists of questions regarding irrigation system design and performance, can be found at http://www.itrc.org/reports/icbr/icbr.pdf. Additional information on the Bills can be found in other ITRC reports (use the search engine at www.itrc.org).

The original idea was that irrigation dealers would sit down with customers and review the questions provided in the Bills, in order for both customers and dealers to reach a common understanding of desired performance and technical issues. The customer would know what was being purchased, and the dealer would have a well-informed customer. The intended result was less hassle and better performance. In reality, only a few irrigation dealerships utilize the ICBR. It remains a valuable, if underutilized, tool that can also be helpful for cost-sharing programs. The Bills could be tailored with district-specific questions and answers (which the ICBR did not include) for any given program. Discussion and recommendations for some key parameters are outlined below.

Distribution Uniformity (DU). The concepts and computations of a global, system distribution uniformity (DU_{lq}) for a drip system are well established (Burt, 2004 and Burt et al, 1997). The word "system" is emphasized because the DU must account for variations across a whole field, not just along a single hose. New drip/micro irrigation systems should be guaranteed to have a system DU_{lq} of better than 0.92 (1.0 being perfect), to include all variations in emitter pressure (friction, elevation change, pressure regulator valve variations) and emitter manufacturing variation.

Field Flow Rates. Some programs recommend specific flow rates for a given crop and area. However, the flow rate requirement issue is not so simple.

A huge component of the decision involves selecting the proper "down time" of the system. If a pump only operates for half the time (as compared to 100% operating time), the system flow rate must be doubled. That, in turn, requires twice the horsepower (HP) (but the same HP-hours per year), larger filters, and larger mainline pipe. There are excellent reasons for operating less-than-100% of the time during the period of peak irrigation water demand. These include:

- *Electric utility time-of-use rates*. Farmers may be able to obtain substantially lower dollar per kilowatt hour rates if they agree to not pump for certain hours of the week.
- *Cultural operations*. There may be a need for certain tractor or spraying activities that are not compatible with irrigating at the same time.
- *Safety factor*. It's not a question of if things will break – it's only a question of when.

A second question involves the net depth of water required per day or week or month. It is common to use average monthly ET values, and divide by the number of days in the month (for example, thirty-one days for July). By definition, however, an average value is not big enough to cover the month during an unusually hot year, and dividing by thirty-one days per month assumes that the ET for each day is the same, which is untrue. On the other hand, designers know that if they design for the hottest day of the hottest month, the cost will be outlandish. Essentially, this is a question that the grower must answer: How much of a gamble is the grower willing to take when balancing cost and adequate irrigation? Different growers will have different answers; there is no single correct answer. For example, a grower who only has one year to pay off a loan cannot invest as much in a system as another grower might. What is important, and what the ICBR attempts to promote, is that both grower and designer are clear on expectations.

A third question regarding flow rates is how "Irrigation Efficiency" or "DU" are used to obtain a gross flow rate from a net requirement (just looking at ET and hours). If one goes back to the original development of the DU_{lq} concept, that value was intended to be used for irrigation scheduling as follows:

$$\text{Gross to apply} = \frac{Net\ Required}{DU_{lq} \times \left(1 - \frac{\%\ surface\ losses}{100}\right)} \quad (1)$$

The focus was to avoid under-irrigation. By using the "low quarter" (lq) concept for DU in this equation, only one-eighth of the field would be underirrigated and the underirrigation on that small part of the field would be minimal. The argument was that it was not worth it to adequately irrigate the entire field, and that slight under-irrigation of one-eighth of the field was much more economical.

However, there is another way to view this computation. This scenario guarantees that there will be deep percolation on seven-eighths of the field. The question for an irrigation district that is trying to minimize high water table problems is simple: Is this a desirable goal? Or should the DU_{lq} be eliminated from the equation above? If it is eliminated, half of the field will have deep percolation, and half will have under-irrigation. It is an interesting discussion item. It is important to point out, however, that if the DU is very good, it does not really make much difference. For drip/micro systems, the gross should be very similar to the net required. So why do cost sharing programs not require a guaranteed high new DU, plus the proper filtration and chemigation equipment, to help ensure that the DU will remain high over time?

Many customers and dealers focus on the flow rate of the emitters or tape. That flow rate number should not directly enter into this conversation. The numbers of interest are (i) the flow rate of the pump, and (ii) the total acreage irrigated by that pump.

As a general guideline, the following specification provides for time-of-use electrical demand and reasonable results :

- Design a drip/micro system for 17 hours of operation per day during peak ET period.
- For the peak ET, use the published average peak monthly ET value, multiplied by 1.05
- For the DUlq, use a value of 0.82. This assumes eventual deterioration of performance (from the 0.92 at the start).
- Assume no surface losses, as extra evaporation should be built into the peak ET number.

<u>Chemical Injection</u>. Both nutrient and maintenance chemicals need to be injected through drip systems. Well informed farmers have numerous chemical tanks at the filter site, while those with less knowledge about the subject have one or none.

There are two common, significant problems with many common installations in regard to chemical injection:

1. Not enough injection points or injection pumps are supplied. Every chemical needs a different pump and meter and injection point because:
    a. Mixing chemicals often creates compatibility problems (i.e., things plug up)
    b. Different chemicals have entirely different flow rate requirements (e.g., nitrogen will be injected at a higher rate than a special polymer to inhibit iron problems)
    c. Chemicals can't be spoonfed if only one chemical can be injected at once.
2. Many chemicals are injected downstream of filters rather than upstream. This requires that the designer and farmer address several issues:
    a. The system must be designed to stop chemical injection during filter backflushing, or else the backflush water (minus the dirt) needs to be recirculated. Commercial equipment is readily available for both solutions.
    b. A common complaint is that the filters backflush all the time, so it is impossible to stop chemical injection during filter backflush. This means something is wrong with the filter system.
    c. Some growers damage their filters by injecting high dosages of strong acids. In most cases, however, strong acids are not necessary. In many soils, it is very easy to drop the pH but almost impossible to raise it again. And hoping that strong acids will adequately dissolve carbonate precipitation on emitters is a bit of a gamble.

d. The big exception to the upstream injection recommendation, of course, is pesticides. Those should always be injected downstream.

Basic recommendations are as follows:

- Install an approved backflow prevention valve before any injection points, if the water supply is a well or the source water could be contaminated by backflow.
- Install four injection points upstream of the filter, and two downstream.
- Install five outdoor receptacles that can power injector pumps with 20 amps each, 110 V.

Flow meter. Use a full spool flow meter with a pulse or 4-20 mA output that can be connected to fertilizer injector for proportional injection. The flow meter must be installed with upstream and downstream dimensions that conform to manufacturer requirements.

Adequate Filtration. The first truth about filtration of surface water is that there is rarely enough attention paid to “prefiltration”. Almost all drip/micro filters (disc, sand media, screen) are polishing filters. They are incapable of adequately handling large particles and very heavy dirt loads. That is the task for settling ponds, rotating screens upstream of the pump, etc., known as prefiltration. Additionally, for well pumps, starting a pump slowly with a variable frequency drive controller works exceptionally well to minimize the large amounts of sand and dirt that can show up when a typical well pump starts up. For canal deliveries, irrigation districts should investigate the most applicable pre-filtration devices, and then specify those as requirements.

The author of this paper has personal preferences for the "polishing" filtration. For simple sand problems, the best option can be a screen filter with internal rotating wands. For almost anything else, the author recommends media tanks. Still, there are huge differences in the quality, ease of maintenance, and ease of operation of various models and brands. ITRC recently published a report on sand media filters that points out recent improvements in sand media filtration (http://www.itrc.org/reports/mediafilters.htm).

Once the required prefiltration and the correct type of filter are present, there must be standards or guidelines for the proper size or number of filters. The filter number and size are highly dependent on water quality as well as the size/type of emitter in the field. Without adequate guidelines, farmers are faced with multiple vendors selling multiple sizes of filters for the same flow rate and water quality. The ITRC recommendations for media tank sizing are shown in Table 1.

Table 1. Recommended sand media tank sizing (Burt and Styles, 2011)

Irrig. System Flow Rate, GPM		**Number and Size (Dia) of Tanks**
Moderate Dirt Load	Moderately Heavy Dirt Load	
50	35	2 - 18"
100	70	3 - 18"
150	105	3 - 24"
175 – 275	122 – 192	3 - 30"
276 – 425	193 – 299	4 - 30"
426 – 575	300 – 399	4 - 36"
576 – 775	400- 539	3 - 48"
776-1025	540 – 719	4 - 48"
1026-1275	720 – 899	5 - 48"
1275 – 1525	900 – 1069	6 - 48"
1526 – 1675	1070 – 1170	7 - 48"

Pump Efficiency and Power. This is important because of ongoing operation expenses. There are three major items to highlight:

1. It is almost impossible to perfectly match one pump to all of the various flow rate and pressure combinations that one encounters in a drip system when considering various backflush flows, different block sizes, different block elevations, etc. The simple solution is to select a good large pump and use a variable frequency drive controller to avoid excess power consumption when it is not needed.
2. The minimum acceptable pumping plant efficiency should be specified. Recommended new pumping plant efficiencies should be 72% or better.
3. Even with an excellent efficiency, a pumping plant might still be pumping much more pressure than necessary. Typical wastes of energy in drip/micro systems are:
   a. Valves that require large (e.g., 20 psi) pressures just to open, even though the manufacturers report only 1-3 psi friction at the design flow rate (without mentioning that the valve will not open at low pressures). This is an important consideration for drip tape systems. If drip tape systems are cost-shared, the valves should be specified to have no more than a 4 psi loss while delivering the desired discharge pressure.
   b. Designers under-design the backflush piping on drip systems, and think that media tanks need 35 psi to backflush properly, which is not true. However, other filters actually require 35 psi, minimum, to operate properly.
   c. Poor designs have very long hoses (albeit with pressure compensating emitters) and small pipes and small valves, plus a conservative “10 psi” or so added as a buffer amount.

   On flat ground, the system should be designed for a total inlet pressure to the system of less than 35 psi.

CONCLUSION

It is easy to set up a simple cost sharing program for drip/micro irrigation systems, but programs must be carefully structured to maximize all benefits that are achievable. Growers and districts must recognize that their goals may be different, and any program must be tailored accordingly. Additionally, proper education regarding drip system design is vital in order to ensure that any program encouraging the switch to drip/micro irrigation will succeed.

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THE SAN JOAQUIN RIVER RESTORATION AND POTENTIAL IMPACTS TO ADJACENT CROP PRODUCTION

Roger Burnett[1]

ABSTRACT

A Stipulation of Settlement of a lawsuit between the Natural Resources Defense Council (NRDC), the U.S. Department of the Interior (USDI) and the Friant Water Users Authority (FWUA) was reached in September of 2006. The Settlement includes two objectives. The first is a commitment to restore flows and salmon to the San Joaquin River between Friant Dam and the confluence with the Merced River in California. The settlement requires specific releases of water from Friant Dam designed primarily to meet the seasonal life stage needs for spring and fall run Chinook salmon. The second objective is to reduce or avoid adverse water supply impacts to all of the Friant Division long term contractors that may result from the release of water for these restoration flows. An additional group of downstream entities, including several local water districts and organizations of landowners expressed concern that additional flows in the San Joaquin River may impact their crop production through rising ground water levels and increases in soil salinity. This group has been defined as "Third Parties" and has valid concerns regarding the current and future impacts on agricultural production adjacent to the San Joaquin River.

Starting in October of 2010, water was released from Friant Dam as interim restoration flows to the San Joaquin River. The interim flows followed a prescribed release pattern to begin to study the effects on the river channel and on the adjacent agricultural lands. Data collection from monitoring wells and selected soil salinity sites began to document both the pre-interim flow conditions and the potential third party impacts. Interim flow releases have been adjusted to lower flow rates to avoid crop rootzone water logging in the lower reaches of the study area.

This paper is a discussion of the activities undertaken to define, monitor, and where possible propose to mitigate, the concerns of the "Third Parties". Reclamation has established a public outreach and continues to work with these water districts and individual agricultural producers to share information and cope with changes in the river system hydrology. A bulk of this effort has been the establishment of the Seepage Management Plan and the implementation of a monitoring network to track the changes in the shallow ground water levels and the soil salinity trends.

INTRODUCTION

A Stipulation of Settlement of a lawsuit between the Natural Resources Defense Council (NRDC), the U.S. Departments of the Interior (USDI) and the Friant Water Users Authority (FWUA) was reached in September of 2006. The Settlement includes two

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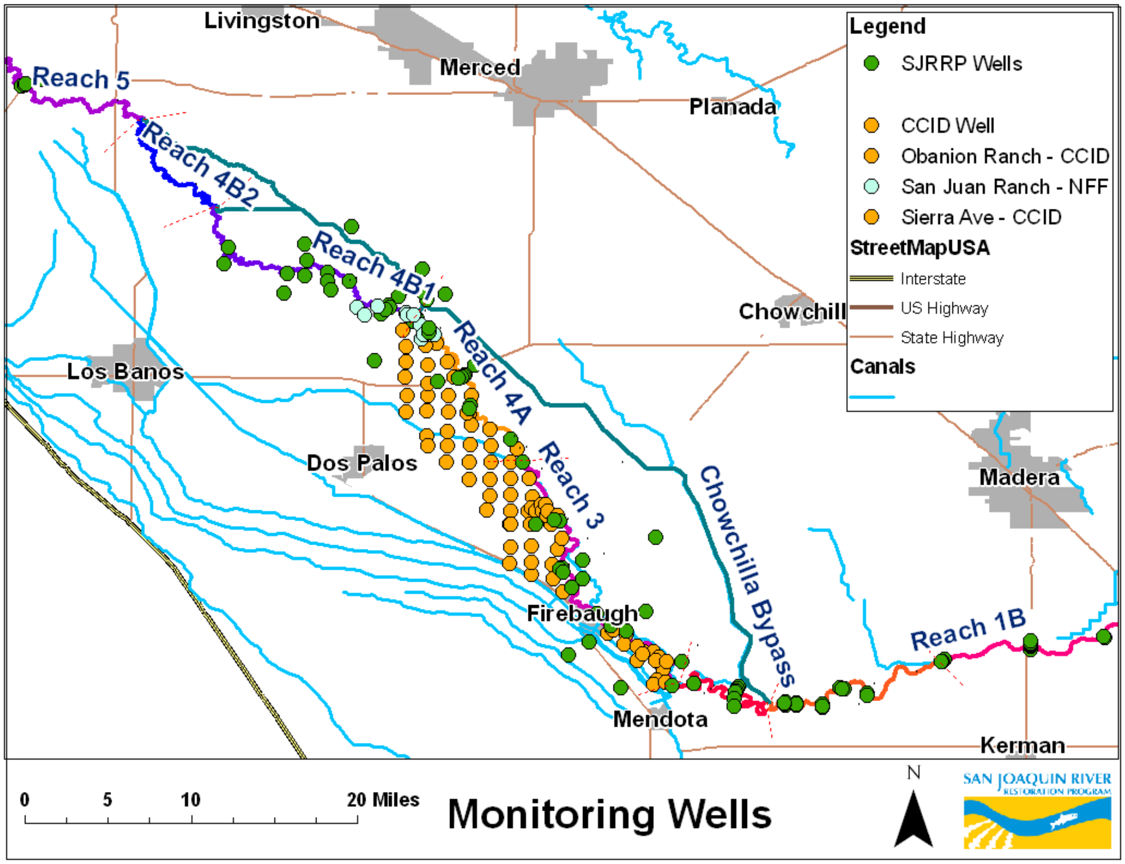
objectives. The first is a commitment to restore flows and salmon to the San Joaquin River between Friant Dam and the confluence with the Merced River in California. The settlement requires specific releases of water from Friant Dam designed primarily to meet the seasonal life stage needs for spring and fall run Chinook salmon. The second objective is to reduce or avoid adverse water supply impacts to all of the Friant Division long term contractors that may result from the release of water for these restoration flows. An additional group of downstream entities, including several local water districts and organizations of landowners expressed concern that additional flows in the San Joaquin River may impact their crop production through rising ground water levels and increases in soil salinity. This group has been defined as "Third Parties" and has valid concerns regarding the current and future impacts on agricultural production adjacent to the San Joaquin River.

The Seepage Management Plan is a communication document that relates San Joaquin River Restoration activities and potential seepage damage thresholds to the landowners. The Seepage Management Plan is not a static document and will be revised as new data is discovered during the early years of the restoration flows in the river. The relationships between the river flow and stage, and the changes in ground water levels and salinity are being documented and will likely require some additional years of data to fully develop.

SAN JOAQUIN RIVER STUDY AREA

The general location of the restoration flows is in a reach of the river from the outlet of Friant Dam to the confluence with the Merced River. This comprises about 150 river miles and is subdivided into five general river reaches for the purposes of study and monitoring. The upper reaches, nearer Friant Dam, contain a section of gravelly river bottom and are important to the future spawning and return of the salmon. The middle and lower reaches, below Mendota Pool, have had historically low flow or no flow for various months and years since the completion of Friant Division.



.Figure 1. General Location and Monitoring Well Network

GROUND WATER MONITORING WELL NETWORK

Ground Water Monitoring

Ground water monitoring has been established with an initial set of wells installed along transects at about a ten mile spacing along the river. Some of the wells have been fitted with real time transducers and transmitters. Some of the wells, based on their location, have been identified as key indicators of the ground water conditions adjacent to the river channel, and these key wells are the indicators of changing ground water depth trends. The following figure shows the well network as it exists today. More monitoring wells are being installed in the area in response to specific landowner or water district concerns and also in support of some special studies.

Depth to Water Table

For agricultural production, the depth to water table is important from the standpoint of a crop rootzone depth. There has been much discussion on this topic as it pertains to various crops and the use of crop rootzones for all crops considered in a crop rotation. The historic depth to the water table is quite variable throughout the 150 mile corridor of the study area. Generally the areas with historic shallow depth to water are now the areas of greatest concern due to the minimal amount of room for the water table to fluctuate without encroaching on a crop rootzone. The following figure is an idealized concept of a crop rootzone and the depth to ground water measured in a monitoring wells.

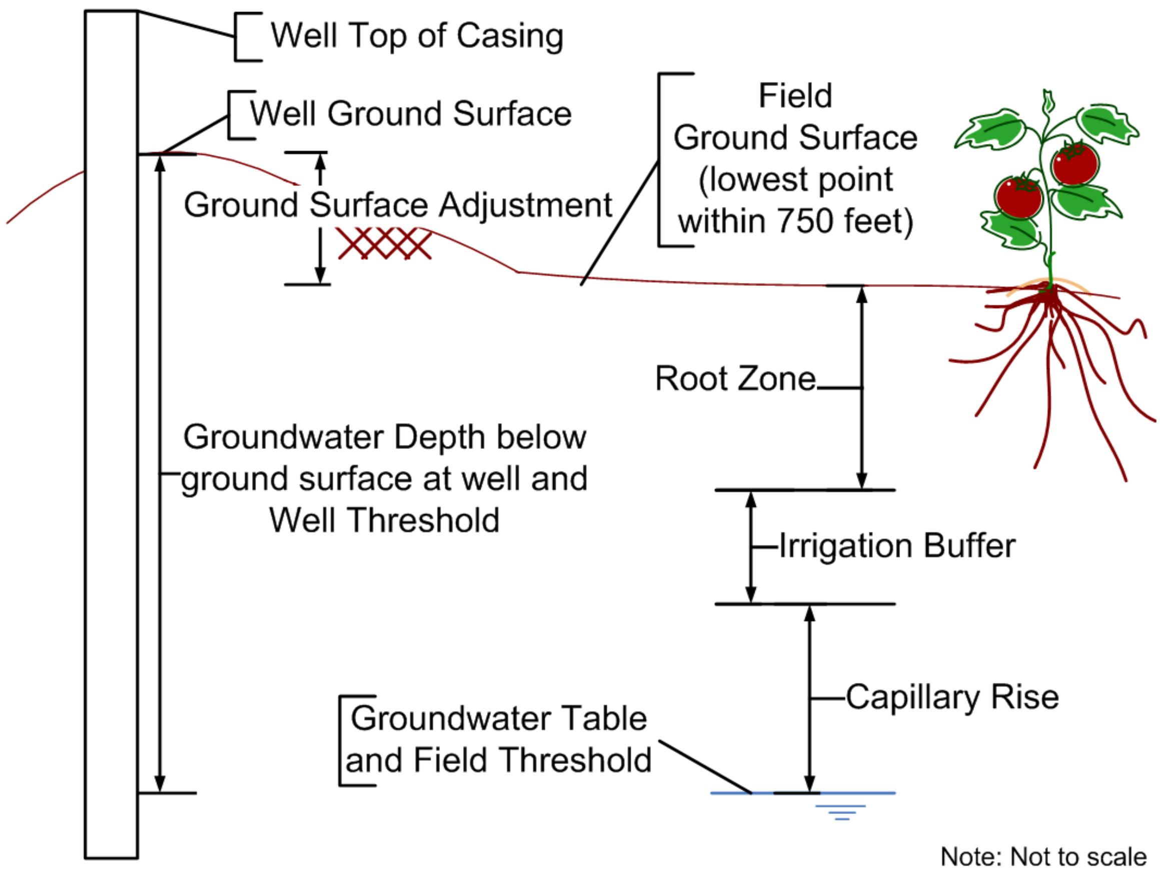


Figure 2. Idealized Rootzone and Depth to Ground Water

The depth to the water table, as measured in the monitoring wells, does require a little bit of interpretation before it can adequately be related to a crop rootzone. This is due to the site location of each well and the relative difference in elevation with the adjacent agricultural field ground surface. An additional elevation (or depth to the water table) adjustment has been included to provide some consideration for the capillary fringe of near saturated soil just above the water table. Some capillary fringe water can be beneficial by providing a portion of the crop water requirement; however, the mostly saturated and more anoxic portion of the capillary fringe near the water table is not conducive to plant root development. This anoxic portion of the capillary fringe has been estimated in general terms and has been included as a part of the rootzone requirement. An additional subsoil space, shown as "irrigation buffer", has been added to accommodate a water table buildup associated with an irrigation application. Crop settings that have the benefit of tile drains are less likely to need this extra buffer because the tile drains normally would remove the deep percolation from irrigation in a timely manner to prevent crop root damage. The following figure illustrates a threshold depth to water in a monitoring well. When the water level in the monitor well reaches the buffer threshold, the well and the surrounding area are considered to be at risk of crop damage and the area rises to become a level of concern with the monitoring team.

The monitoring wells throughout the study area exhibit a range of ground water conditions. Consider the following figure that is a transect of wells in the upper reaches of the river (closer to Friant Dam) where the restoration flows have little impact on the surrounding agricultural crops. This is an area of the San Joaquin River that has extensive ground water pumping and thus a deeper overall depth to the water table.

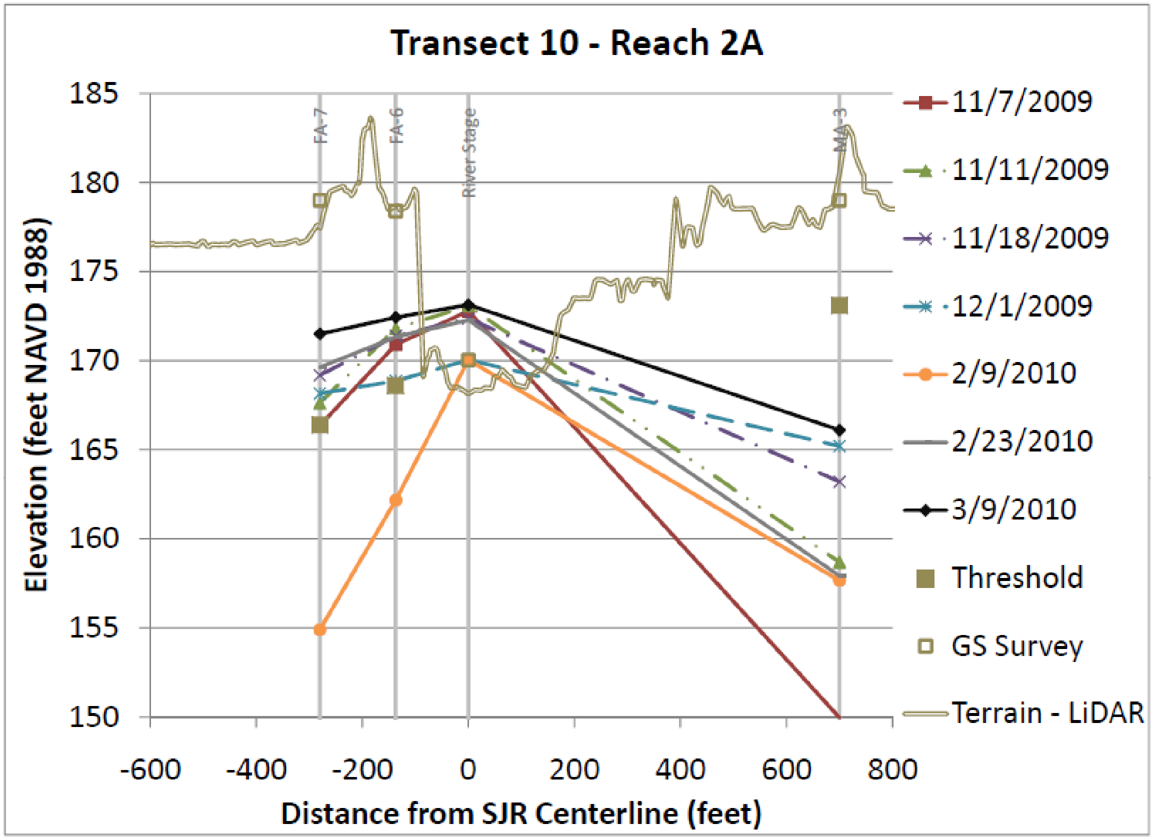


Figure 3. Ground Water Cross Section in Reach 2A

This next figure illustrates a common scenario in study reaches three, four and part of five. This area of the river has had a history of shallow ground water levels. The increased water levels in the San Joaquin River have the effect of recharge under the adjacent land as well as limiting the adjacent land drainage toward the river channel.

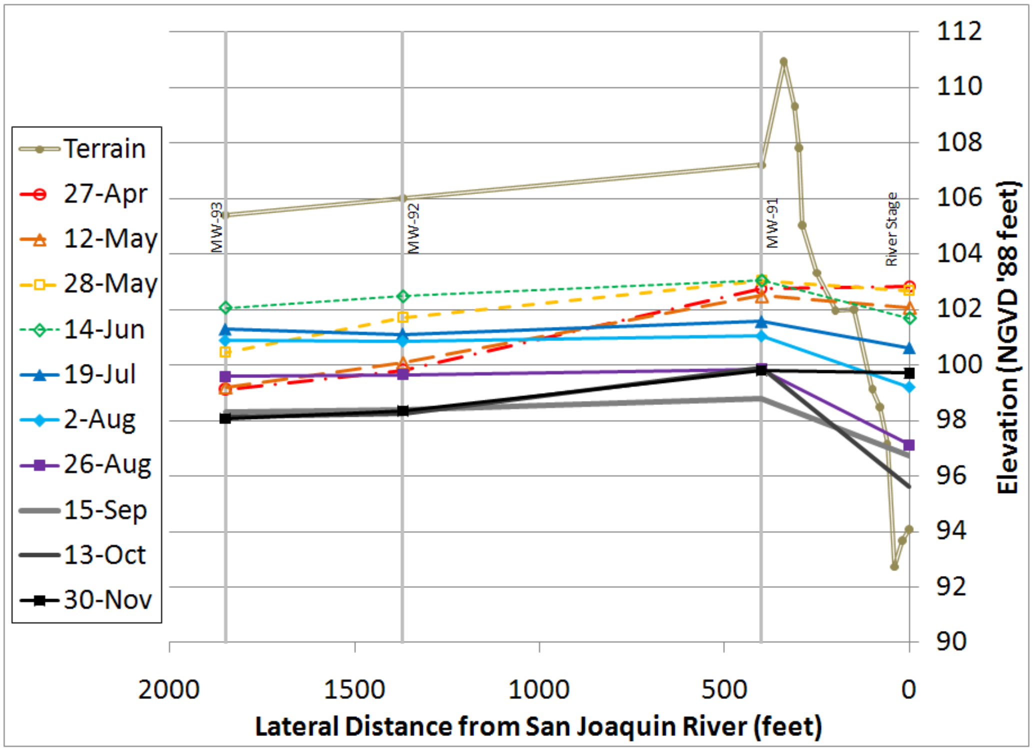


Figure 4. Ground Water Cross Section in Reach 4A

The following hydrograph of monitoring wells 186A and 191 show water table fluctuations since 1981. Note the general shallow depth to the water table in well 186A, and the limited rootzone of 3.5-4.0 feet below ground surface.

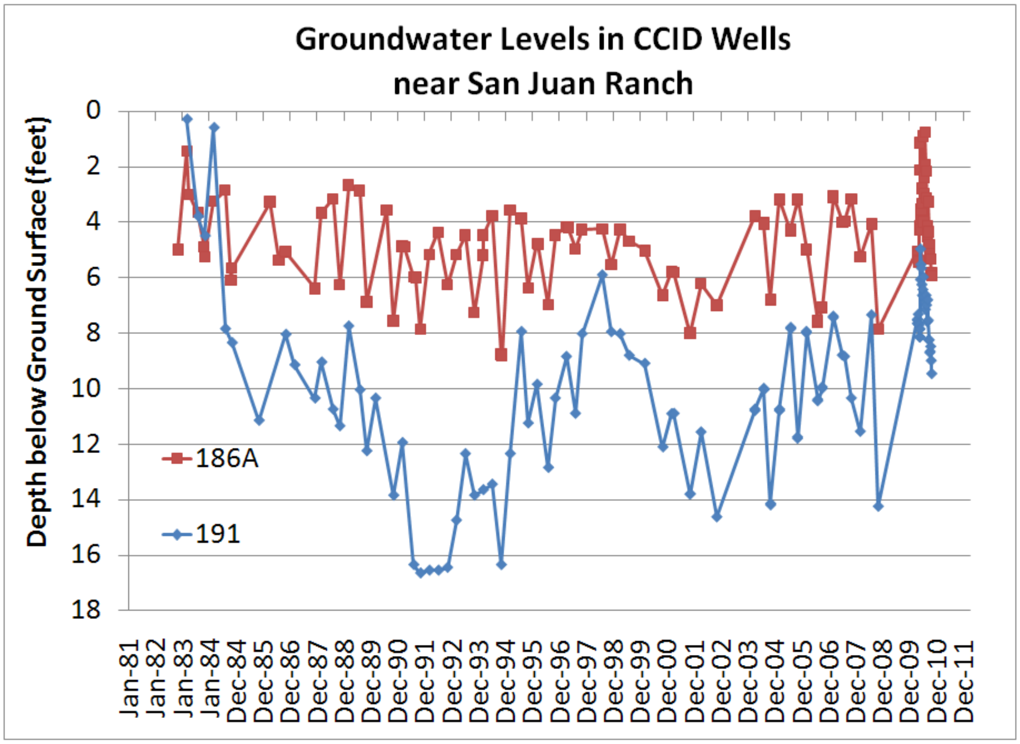


Figure 5. Historical Hydrograph of Monitoring Wells 186A and 191

Realtime Monitoring Wells

Several wells within the study area have been fitted with transducers and transmitters for realtime data access. These wells are listed on the San Joaquin River Restoration Program website (http://www.restoresjr.net) and are included in the state of California Data Exchange Center website. (http://cdec.water.ca.gov)

SOIL SALINITY MONITORING

The depth to the water table can be a key factor in the upward movement of water and salts. This movement of salts into the crop rootzone can produce conditions unfavorable to many of the more salt sensitive crops grown along the San Joaquin River. The growers in the area have established crops and cropping patterns that have been compatible with the history of the river flows since Friant Dam and the Friant Division were constructed in the 1940s. Changing the river hydrology, by introducing more ground water recharge, has the potential to raise the shallow water table and induce more upward groundwater and salt flow. Every field along the 150 miles of the San Joaquin River cannot be measured, but selected sites can be established as monitoring points to see if there are changes in salinity relating to changes in the river hydrology.

In 2010 there were 77 sites that were established as benchmark sites. Soil samples for salinity analysis have been recorded for depths of 0-12 inches, 0-30 inches, and 30-60 inches. Additionally, a Geonics EM38 soil conductivity meter was used to gather salinity data within a 100 foot radius of each sampled site. Salinity has been documented at these sites in the spring with all sites sampled between February and March. Sampling each spring is expected to show trends that could be associated with long term changes in soil salinity and not the seasonal increase and decrease with evapotranspiration and irrigation induced effects. Springtime soil salt distribution in the fields is expected to be more uniform than at other times of year due to winter precipitation and application of leaching water. This should be the time of year when soil salinity is at the lowest. It is expected that if soil salinity is increasing, then the trend should be indicated by a general rising salinity from year to year. The ranges of soil salinity measured in the 77 sites are shown in the following table.

Table 1. Range of Soil Salinity

Soil Depth	Maximum, dS/m	Minimum, dS/m	90^{th} Percentile
0 - 12 inches	13.85	0.16	4.89
12 – 30 inches	9.89	0.31	5.16
30 – 60 inches	9.99	0.11	4.60

This table illustrates the wide range of soil salinity in the existing setting. The maximum salinity is located on a site somewhat out of the program area, so the 90^{th} percentile has been shown to indicate more of the range of soil salinity in the area close to the San Joaquin River. Comparing the year 2010 to the 2011 sampling data, overall there were no major changes in soil salinity in the top 30 inches of soil (active root zone). However a closer look at the data seems to indicate that soil salinity generally increased in Reach 2a, decreased in Reach 2b, and increased somewhat at sites close to the river in Reach 4a. Areas in Reach 4b near the eastside bypass generally remained saline. Soil reclamation of these lands is inhibited by historically high groundwater levels.

TILE INTERCEPTOR DRAINS

One of the proposed remedies for the support of continued agricultural production is the use of tile interceptor drains. Other possible remedies may include easements allowing growers to manage their own solutions, drainage ditches, shallow groundwater pumping, slurry walls, and acquisition. Tile interceptor drains could be installed parallel to the river channel and at depths deep enough to protect the adjacent crop rootzones. The use of interceptor drains could offer some control of the water table and may need to be used in combination with a second spaced drain farther from the river in order to adequately control the water table. Investigations of the subsurface site conditions would be required to determine if one or more tile interceptors would be needed to control the water table.

Site Specific Field Data

To date there has been some field data collected along the west side of the San Joaquin River in reach four. Subsurface soil hydraulic conductivity tests have been done to determine the permeability of the subsurface and the ability of the substrata to conduct groundwater. An existing interceptor drain has been fitted with a flow meter on the discharge and a few local monitoring wells show some of the influence of the drain. The discharge is recycled back into the irrigation supply canal. On this particular site, the drain water quality is around 0.95 mS/cm and can be used as an irrigation supply for most crops grown in the area. The following table shows comparative values from samples collected in September of 2010 at river mile 170.

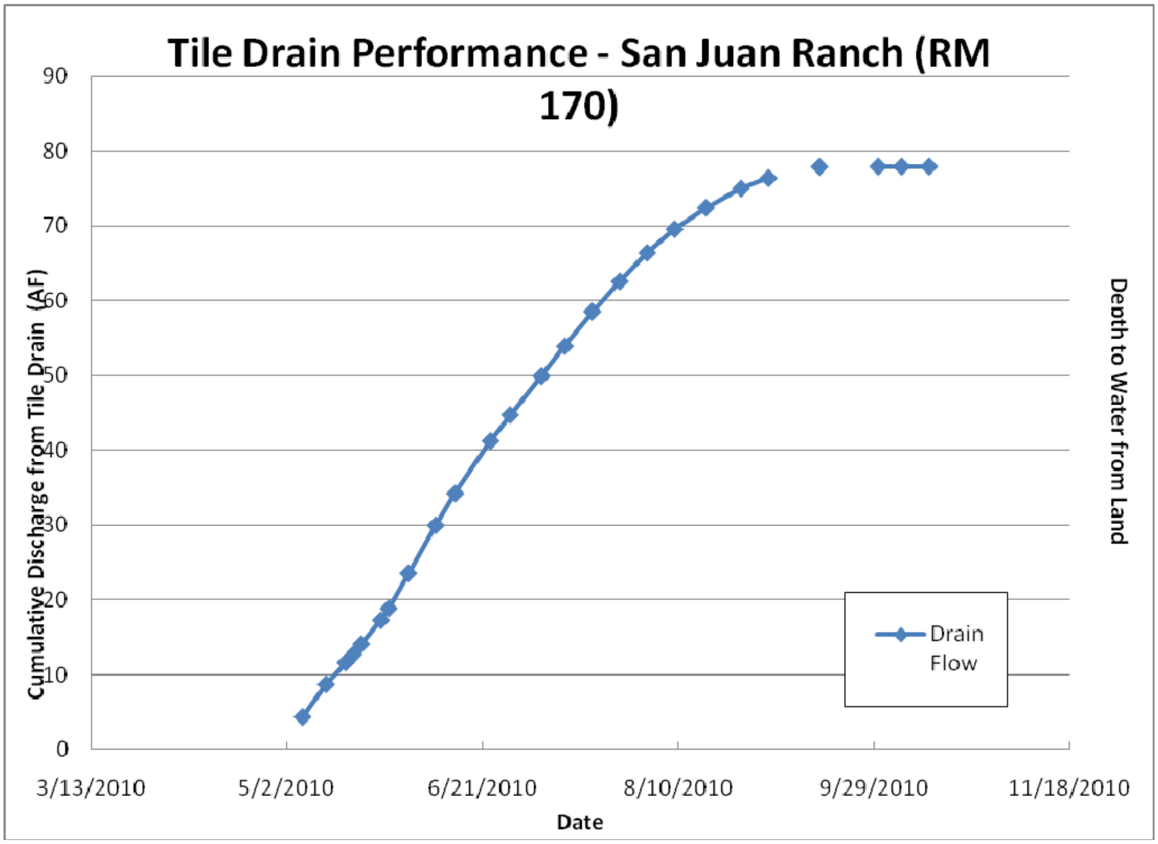


Figure 6. Interceptor Drain Discharge

Water samples were collected in September 2010 and analyzed for major ions, electrical conductivity (EC), and pH. The results show the higher quality river and canal water as compared to ground water under the irrigated field. Well MW91 is near the river channel and on the edge of the irrigated field. Wells MW92 and MW93 are located out in the irrigated field and are at distances of 1155 Ft and 2300 ft from the river channel. The water quality at well MW91 shows the influence of river and canal seepage. Wells MW92 and MW93 show the influence of irrigation deep percolation.

Table 2. Water Quality of River vs Ground Water at River Mile 170.

Sampling Site	**pH Cl**	**(mg/L)**	**Leaching Fraction**	**EC (µS/cm)**
San Joaquin River	8.1	51		440
Riverside Canal	8.5	58		435
Tile Drain Effluent	7.4	120	48%	942
MW-91	7.5	110	53%	908
MW-92	7.2	240	24%	3368
MW-93	6.7	860	7%	4086

CONCLUSION

The San Joaquin River Restoration Program is in the beginning years of development. The flows of surface water that have been re-introduced into the river channel have been monitored for impacts on adjacent land. The effects of a continually wet river channel are still being monitored and evaluated. Monitoring efforts have been focused upon the depth to the water table and the potential changes in rootzone salinity. The monitoring program continues to be defined and refined as new data develops.

Agricultural production in some areas of the lower reaches has been impacted by historical and continued shallow water tables and salinity. The use of an interceptor tile drain placed parallel to the river channel has promise in controlling the water table buildup caused by river seepage loss. The discharge quantity and quality of any future proposed interceptor tile drains may be the biggest challenge to overcome before any drainage project can be attempted.

ACKNOWLEDGEMENTS

The San Joaquin River Restoration Program, US Bureau of Reclamation, Sacramento, California

REFERENCES

The San Joaquin River Restoration Program, US Bureau of Reclamation, Sacramento, California

The Seepage Management Plan, US Bureau of Reclamation, Fresno, California

San Joaquin River Restoration Program (SJRRP); Seepage Management Team; Soil Sampling Report Year 2011; August 21, 2011 draft; Joe Brummer; Soil Scientist

IMPERIAL IRRIGATION DISTRICT-SAN DIEGO COUNTY WATER AUTHORITY WATER TRANSFER
WATER FOR TRANSFER BY EFFICIENCY CONSERVATION — ACTIONS AND CONSEQUENCES

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ABSTRACT

The Imperial Irrigation District (IID) and San Diego County Water Authority (SDCWA) began implementation of the nation's largest and longest "ag-to-urban" conserved water transfer in the fall of 2003. The IID-SDCWA transfer could not occur until the parties had resolved legal and environmental challenges to their right to implement the transfer. Equally daunting was the effort to reach agreement on an economic arrangement that could fund a flexible IID water conservation implementation plan for hundreds of thousands of acre-feet per year that would be adaptable to changing circumstances during the 45-year transfer term, and also fund environmental mitigation and socioeconomic assistance. To accommodate environmental and technical complexities, a graduated ramp-up schedule and conservation method phasing were made part of the agreement. Turning these parameters into an implementable water conservation plan was a substantial engineering challenge. Numerous legal, political, economic, environmental and technical hurdles have been overcome since the implementation of the transfer began in 2003. Other hurdles remain, and are continuing to be addressed.

INTRODUCTION

From the 1930's to the recent past, water users within the State of California used about 800,000 afy[4] more than available under California's long term reliable water rights to the Colorado River. IID holds California's largest and one of the most senior water rights to the Colorado River. The Metropolitan Water District of Southern California (MWD) is a wholesale water supplier to most of urban Southern California, and has the lowest priority to California's share of the Colorado River, and a reliable right to less than half of MWD's historic use of the Colorado River. MWD's other principal water supply source is the California State Water Project, a supply at risk because of its impacts on the environmentally precarious Bay-Delta. As other states with Colorado River water rights (Basin States) pressured California to reduce its total Colorado River use to the maximum

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[4]The term "af" is used for acre-foot; "afy" means acre-feet per year; "kaf" means acre-feet in thousands; "maf" means acre-feet in millions. An acre of water foot is generally considered sufficient to satisfy one rural family of four for a year, or two urban families of four.

amount available under its water rights, IID's large and senior water right was looked at with covetous eyes by many as a potential replacement supply for urban Southern California. The historic IID-SDCWA conserved water transfer is in direct response to efforts by IID to protect and preserve its large senior water right, while at the same time assisting urban Southern California satisfy its needs for a replacement Colorado River water supply.

HISTORY IN THE MAKING

The Key Players

IID was formed in 1911 as a California irrigation district to supply Colorado River water to the Imperial Valley. IID is a local public agency, governed by a publicly elected Board of Directors. IID holds water rights dating back to the 1880s that allow it to divert water from the Colorado River and deliver that water to the Imperial Valley for agricultural, municipal and industrial uses.

IID is located in a desert environment between the Colorado River Arizona border on the east, Mexico on the south, Riverside County and the Salton Sea on the north, and San Diego County on the west. IID is the sole source of fresh water for the Imperial Valley, and all of that water comes from the Colorado River. Farming is the principal area business, and a more than one billion dollar agricultural-based economy has grown to take advantage of the plentiful sunshine and mild weather. Year round growing seasons allow farmland to be double and triple-cropped.

IID's state water right and federal contract right to the Colorado River allow IID to divert Colorado River water equating to an average consumptive use of about 3.1 mafa. IID requests water to be released from Lake Mead by submitting an order to the United States Bureau of Reclamation (BOR) pursuant to its federal contract, and then diverts the water at the Imperial Dam into the All American Canal (AAC). IID's distribution system is principally a gravity-flow system that includes the 82-mile AAC, almost 1,700 miles of other delivery canals going to about 6,000 head gates, numerous reservoirs, and over 1,400 miles of drainage ditches. An illustration showing the IID order and delivery process, timing, sequence and water flow path is shown on the next page as Figure 1, followed by Figure 2, which shows a diagram that illustrates in more detail how water flows from the Colorado River through IID's irrigation system, to and through farms and into the drainage system with a terminus at the Salton Sea.

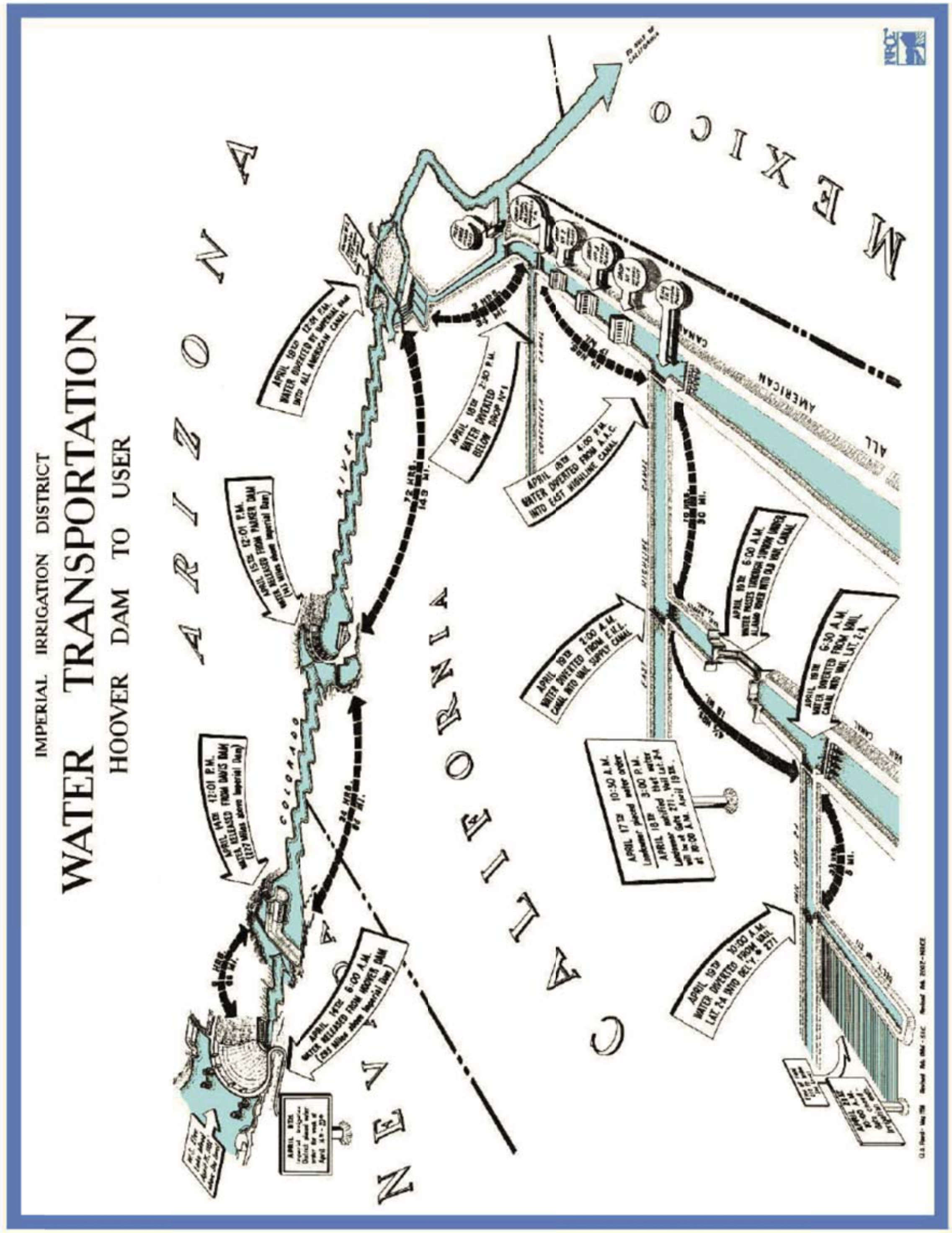

Figure 1. Water Transportation Schematic, Hoover Dam to IID Farmer

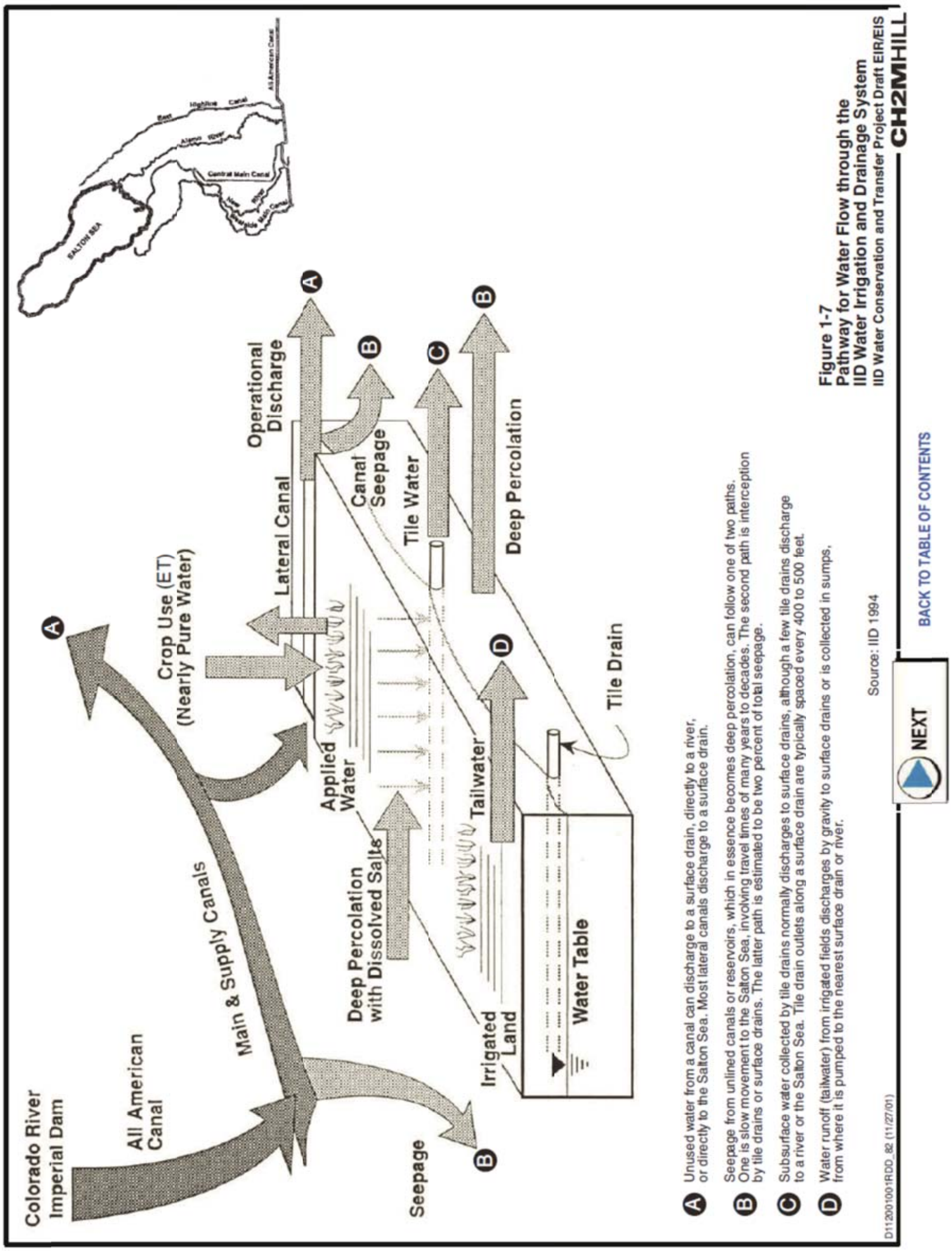

Figure 2. Water Flow Schematic, AAC to Drainage Salton Sea

SDCWA is a wholesale water provider to much of San Diego County. SDCWA is a member agency of MWD, is reliant on MWD for the vast majority of its water, and purchases more water from MWD than any other MWD member agency.

Pursuant to the Boulder Canyon Project Act, the Secretary of the Interior (Secretary) is the water master for the Colorado River for purposes of entering into contracts with those entitled to use Colorado River water and for operating the numerous dams and other works which store and control diversions from the Colorado River. BOR is the agent for the Secretary with regard to fulfilling the Secretary's obligations for operating Colorado River works and delivering Colorado River water, and is historically responsible under the Reclamation Act for water resource development in the western United States.

Dividing California's Colorado River Water

IID's conserved water transfer to SDCWA arises out of historical disputes over to whom and how much California's right to Colorado River water should be divided. On August 18, 1931, a number of existing California Colorado River water users, including IID, and future users, including MWD, entered into the Seven-Party Agreement to establish a consensual division to the use of California's share of Colorado River water. IID and the other applicable California agencies, as well as California, agreed on how California's entitlement to Colorado River would be divided, and what priorities each would receive. The total volume of water divided among the seven California parties is 5.362 mafa.

California's division under the Seven-Party Agreement is reproduced here as Table 1:

Table 1. Seven-Party Agreement

Priority	Description	Acre-feet per year
1	Palo Verde Irrigation District gross area of 104,500 acres	3,850,000
2	Yuma Project not exceeding a gross area of 25,000 acres	
3(a)	IID and lands in Imperial and Coachella Valleys to be served by the All-American Canal	
3(b)	Palo Verde Irrigation District 16,000 acres of mesa lands	
4	MWD and/or the City of Los Angeles and/or others on the coastal plain	550,000
5(a)	MWD and/or the City of Los Angeles and/or others on the coastal plain	550,000
5(b)	City and/or County of San Diego	112,000
6(a)	IID and lands in Imperial and Coachella Valleys	300,000
6(b)	Palo Verde Irrigation District 16,000 of mesa lands	
7	Agricultural Use	All remaining water

Within priority 3(a) and 6(a), where both IID and land in Coachella Valleys are listed, Coachella Valley Water District (CVWD) later subordinated its right to IID. Also, San Diego's 5(b) right was assigned to MWD when SDCWA joined MWD as a member agency. The Secretary incorporated the terms of the Seven-Party Agreement in each of his contracts with the California agencies.

Colorado River water is divided between the Upper and Lower Colorado Basin States[5], and among the states within the two Basins primarily by the 1922 Colorado River Compact and the Boulder Canyon Project Act. Historically, the Upper and Lower Basin States had not been growing in population or Colorado River use at the same rate, and tensions developed among the states, especially with rapidly growing California. The Compact sought to resolve that dispute, but more Colorado River water was actually allocated than was reliably available, especially after the rights of Mexico and Indian Tribes were accommodated.

[5]From north to south: Wyoming, Colorado, Utah, New Mexico (Upper Basin); California, Nevada and Arizona (Lower Basin).

In 1964, after interstate arguments had arisen over Colorado River water divisions and use, the U.S. Supreme Court decreed that California's basic apportionment, when there was no surplus water on the River, was limited to 4.4 mafa. This means that the nonsurplus apportionment for California (4.4 mafa) does not satisfy the allocation listed in the Seven-Party Agreement (5.362 mafa). It is far less.

The public agency with the largest potential shortfall when only 4.4 mafa is available is MWD. MWD brings Colorado River water to Southern California through the Colorado River Aqueduct ("CRA") which MWD owns and operates. The CRA has an approximate capacity of a little more than 1.2 million mafy. Yet, when California receives 4.4 mafa, MWD's priority 4 right is only about 550,000 afa, leaving the CRA over half empty.[6] MWD's CRA was historically operated at full capacity because California historically used far more than 4.4 mafa.

California's use of water above 4.4 mafa was enabled first by low Colorado River water use in Arizona and Nevada. As years passed, Nevada and Arizona began to use their limits, making it necessary for the Secretary to declare annual surpluses on the Colorado River so that California could exceed 4.4 mafa and MWD could keep the CRA full. California's historical use of over 4.4 mafa concerned the other Basin States. They complained about the surplus declarations to the Secretary, and began pressuring the Secretary and California to implement a plan to reduce California's water use to 4.4 mafa.

California's Colorado River Board adopted a draft Colorado River Water Use Plan (California Plan)to reduce California's use to 4.4 mafa. That Plan relied on agricultural water conservation and transfers to urban users (principally by IID). SDCWA became a logical conserved water transferee from IID under the California Plan for various reasons. First, SDCWA was an MWD member agency, and therefore a conserved water transfer to SDCWA would help fill the CRA. Second, SDCWA and MWD had historically argued over how water would be allocated among MWD member agencies in times of short supply. SDCWA used more water on a pro rata basis compared to other MWD members than SDCWA could rely on receiving in times of inadequate MWD supplies. SDCWA desired to develop its own independent and reliable supply by obtaining transferred water from IID.

The IID-SDCWA transfer therefore became the linchpin to solving California's overuse problem. It helped resolve California's problem of increasing the supply to urban Southern California without infringing on the rights of the other Basin States. The transfer is central to peace on the Colorado River and to Southern California having a sufficient water supply.

<u>Specific Disputes Leading Up to the IID-SDCWA Transfer</u>

The IID conserved water transfer to SDCWA also resolved historical concerns by the California State Water Resources Control Board (SWRCB) about the reasonableness (efficiency) of IID's water use. The SWRCB had issued decisions in the 1980s requiring

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[6]Even adding IID's later 1988 agreement with MWD to transfer conserved water of about 100,000 afa, MWD would still be about 450,000 afa short of filling its CRA.

IID to develop a meaningful water conservation plan, including implementing conservation opportunities which could be funded by urban water agencies such as SDCWA. The SWRCB identified approximately 370,000 afa that might be conserved by IID. The SWRCB focused on IID in 1984 in response to the flooding of farmland by the saline Salton Sea. The more efficient the IID became, the less inflow to the Salton Sea would occur, and the flooding risk would subside.

In 1988, the SWRCB conducted further hearings and ordered a conserved water transfer by IID. However, the SWRCB also found that one of the main impediments for IID was funding the conservation that would create the water to be transferred:

> The inability of the District to provide or secure adequate funding for its proposed water conservation program, however, has delayed widespread implementation of specified measures.

SWRCB Water Rights Order WR 88-20, p.18.

Likely sources of funding for IID conservation measures identified by the SWRCB were urban areas in need of water. The SWRCB instructed IID to complete "an executed agreement with a separate entity willing to finance water conservation measures in Imperial Irrigation District," (*Id.*, p.45) or take other measures which would achieve equally beneficial results. The SWRCB retained "jurisdiction to review implementation of the initial plan and future water conservation measures." *Id.* p.44. Pursuant to this mandate, IID entered into a 1988 conserved water transfer agreement with MWD for approximately 100,000 afa. The water transfer with SDCWA is to satisfy the balance of the long-term SWRCB directive.

MWD Seeks to Obtain Some of IID's Colorado River Water Supply

In 1999, MWD wrote a letter to the Secretary asking for stepped-up enforcement of reasonable and beneficial use restrictions. In this letter MWD also asked the Secretary to revisit "whether the public interest warrants continuing the 1931 allocations of Colorado River water . . . . [i.e., water deliveries per the priorities from the Seven-Party Agreement.]" The target of this letter was IID and the proposed IID-SDCWA transfer. MWD wanted to deprive IID and SDCWA of the ability to complete their conserved water transfer and obtain additional IID water for itself without having to pay market prices. Labeling IID water use as wasteful was the strategy to accomplish that outcome.

IID responded unfavorably. The IID Board passed a resolution urging MWD to change its position and authorizing IID legal counsel to take all necessary steps to protect IID. MWD then sued IID and SDCWA to stop the proposed conserved water transfer. This litigation claimed that IID was wasting water, and sought a determination that IID's "wasted" water should not be transferred to SDCWA, but rather be allowed to flow to MWD as a junior right holder.

Concurrently, however, IID, the Secretary and MWD attempted to resolve their disputes. By the end of 2002, despite substantial negotiations and many meetings, no settlement had been reached. The Secretary then forced IID's hand by sending a letter to IID on

December 27, 2002, that stated that if a settlement and transfer arrangement was signed by the end of the year (four days later), IID's 2003 water delivery order would be honored; but if not, IID's order would be cut by 241,100 af. This Secretarial fiat ignored the SWRCB pending jurisdiction over IID water use efficiency, ignored environmental impacts or mitigation needed for a water transfer, and denied IID the financial assistance needed by IID to create conserved water for transfer.

When a settlement was not reached by year end, the Secretary cut IID's water supply as threatened. IID immediately sued the Secretary and obtained a preliminary injunction prohibiting the 2003 reduction. The Secretary then reduced CVWD and MWD deliveries to offset the inability to reduce IID and keep California within 4.4 mafa. Out of this litigation arose a settlement that allowed the IID-SDCWA transfer to proceed.

A remaining stumbling block was reducing environmental impacts and paying for necessary mitigation. IID agreed to create some conserved water by fallowing in the early years of the water transfers, which reduced impacts on the Salton Sea, in exchange for payments from SDCWA to offset socioeconomic impacts.

<u>Salton Sea Restoration and Environmental Mitigation of Transfer Impacts</u>

Because IID's conserved water transfers could have environmental impacts, California Environmental Quality Act (CEQA), National Environmental Policy Act (NEPA) and Endangered Species Act compliance was necessary, required and complied with. The Salton Sea was the single most significant environmental issue faced in the process. The Salton Sea is California's largest lake, located north of the Mexican border at the northern end of the IID service area and the southern end of CVWD's service area. It is in a large depression about 230 feet *<u>below</u>* sea level. The modern Salton Sea was accidently created when the Colorado River breached a head gate and flowed unimpeded into the Salton Sink for almost two years, starting in 1905. The Salton Sea has no significant natural inflow, relying almost entirely on agricultural drain flow from IID and CVWD service areas for its continued existence. The Salton Sea was designated an agricultural drainage sump by the federal government in the 1920s.

During the middle of the 20th century, the Salton Sea was a popular tourist spot, with various resorts built along its shores. However, as inevitable evaporation over the years left behind the salt from the drain water, the Salton Sea continuously became more and more salty and increasingly toxic to wildlife.

When the IID-SDCWA transfer was being negotiated, and *<u>not</u>* as a cause of that proposed transfer, the Salton Sea was already an unhealthy habitat. The Audubon Society labeled it an "environmental Chernobyl" in 1999. Jocelyn Kaiser, "Battle Over a Dying Sea," <u>Science</u>, April 2, 1999, p.28. Massive numbers of endangered species were dying from disease. For example, in 1996 botulism at the Salton Sea killed about ten percent of the entire population of western white pelicans.

Despite this sad environmental condition, the state and federal governments hoped they could save the Salton Sea as a habitat for migratory birds whose native habitat on the

California coast had been lost to urban development. Migratory bird habitat requires the presence of a fishery of some kind to provide food. That, in turn required controlling the ever increasing salinity or creating replacement habitat.

The SWRCB approved the IID-SDCWA transfer, and noted that "restoration of the Salton Sea is in the state and national interest." SWRCB Revised Order WRO 2002-0013, p.41. The SWRCB was concerned that the IID conserved water transfer could possibly preclude restoration: "The conservation and transfer project could foreclose the possibility of restoring the Salton Sea before the state and federal governments have determined whether long-term restoration of the Sea is feasible." *Id*. The SWRCB was fully aware that the State was going to take years to come up with a restoration plan. Therefore, it imposed fifteen years of transfer mitigation to temporarily protect the Salton Sea. Long-range protection of the Salton Sea was legislated to be the State's responsibility.

The IID-SDCWA Conserved Water Transfer

IID's conserved water transfer enables a reduction in water use as a result of water conservation efforts. A ramp-up to 200 kafy for an initial term of forty-five years, with an optional renewal period of thirty years, was agreed to. By limiting the transfer to conserved water from efficiency improvements (other than by fallowing in the early years), farming is not reduced because only newly saved water is transferred. Increasing water use efficiency allows the same farming with less water diverted from the Colorado River. Two sources for efficiency improvements exist for IID: (a) delivery system conservation, by which delivery infrastructure is improved to reduce losses (such as lining canals to reduce seepage, or new structures to reduce spills); and (b) on-farm conservation, by which less water is used to irrigate crops by improving the irrigation methods, such as drip irrigation (for certain crops), slower irrigation, and more level fields. Transfer proceeds will pay for the conservation. Figures 3 and 4 show how crop evapotranspiration is not reduced by transferring conserved water:

In Figure 3, 2.962 mafa is being diverted into the AAC (top right), and crop evapotranspiration is 1.806 mafa (found just above the "On-Farm System" block). In Figure 4, IID's diversions are reduced to 2.602 mafa, more than 300,000 acre-feet less, *yet there is still 1.806 mafa in crop evapotranspiration*. This identical crop consumption is achieved because of delivery system improvements (*compare* "Seepage" and Lateral Spill" losses on the two figures), and also on-farm irrigation improvements (*compare* "Tilewater" and "Tailwater" losses on the two figures).

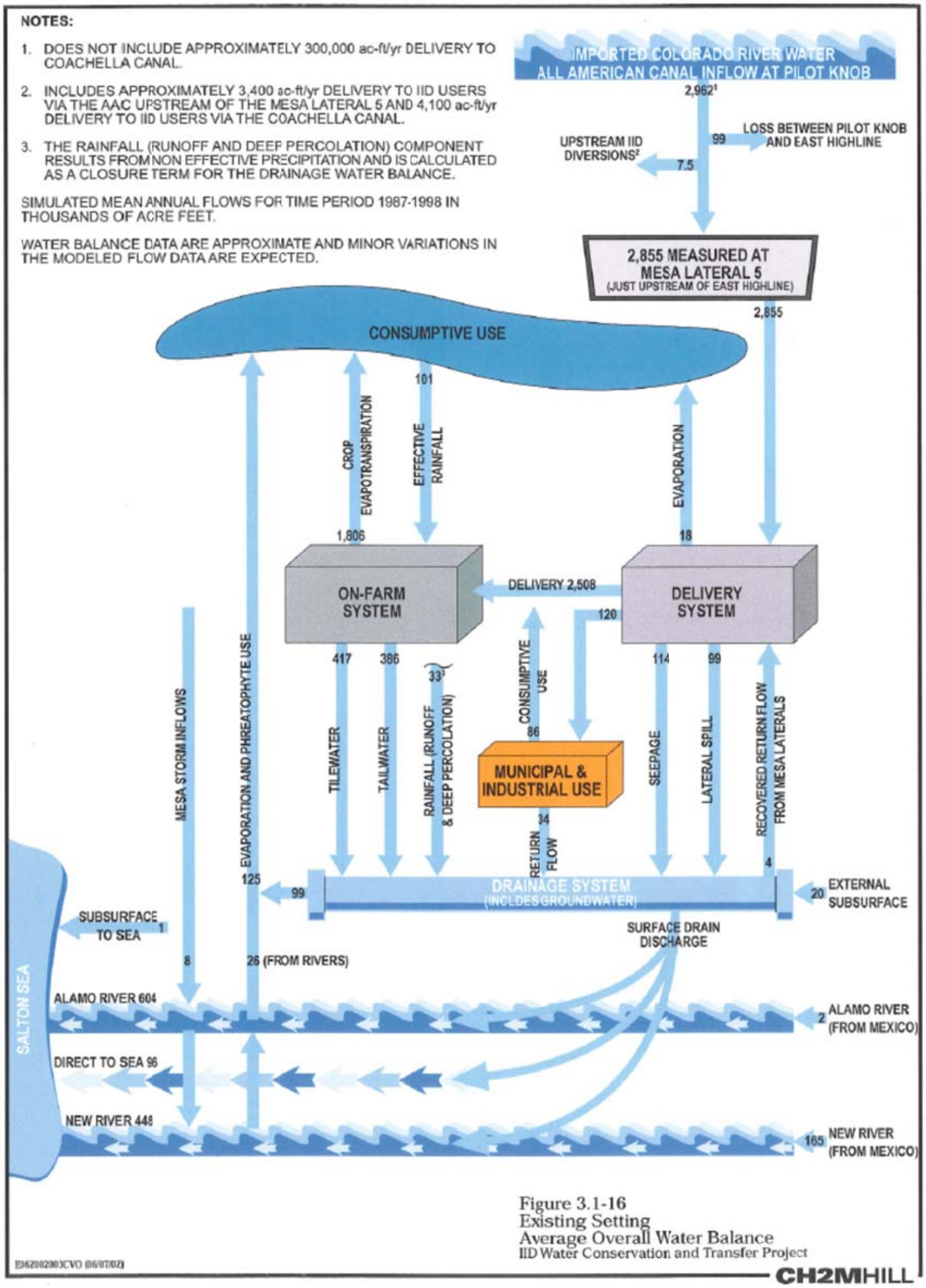

Figure 3. Pre-Transfer Water Balance

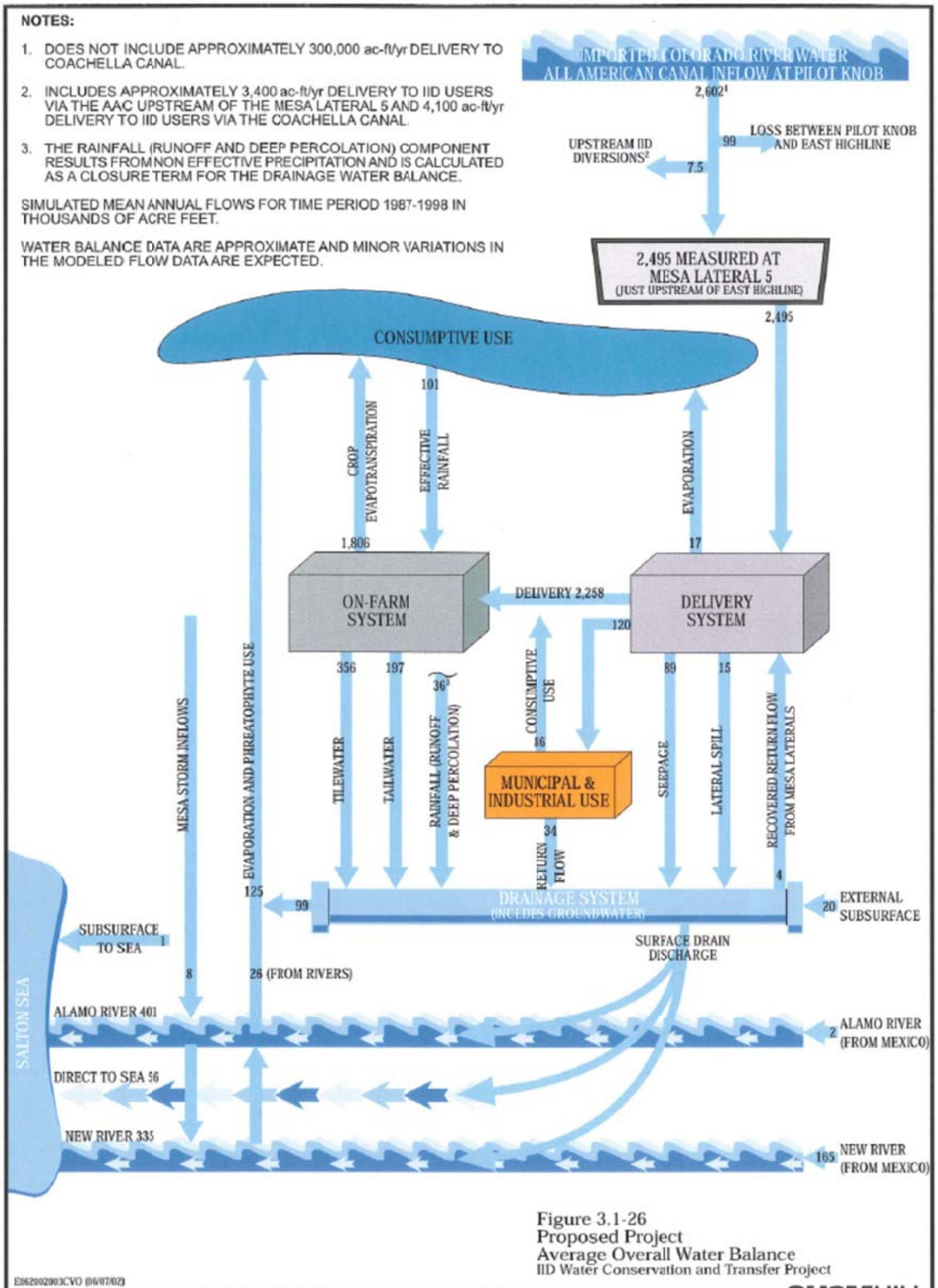

Figure 4. Post-Transfer Water Balance

IID, in return for payment, implements delivery system efficiency conservation, and enters into voluntary contracts with farmers for on-farm conservation to generate water savings. The saved water is transferred to SDCWA and the transfer ramps-up in volume over time.

IMPLEMENTING THE TRANSFER — DESIGN AND COORDINATION OF SEVERAL MOVING PARTS

Reaching agreement on the terms and conditions of the IID-SDCWA transfer was a daunting task. But, designing, developing and implementing the steps necessary to mitigate environmental impacts, reduce socioeconomic impacts and create conserved water for transfer within the confines of the transfer agreement terms also presents serious challenges.

Environmental Mitigation

The Imperial Valley's ecosystem has been significantly modified by the irrigation infrastructure and agricultural activity it supports. This combination of natural and anthropogenic forces has resulted in a unique setting that supports a diverse plant and animal community. Preserving and protecting that community from adverse impacts is an integral part of the IID-SDCWA transfer. Numerous permits and approvals, including state and federal Endangered Species Act permits and CEQA findings outline over 100 specific mitigation measures designed to avoid and minimize effects to the biotic and abiotic resource. While the permit and document requirements outline the mitigation requirements, the real challenge is in the interpretation, implementation and management of those measures. IID established a mitigation implementation team with the wildlife agencies in order to design, manage and monitor the mitigation activities. IID also developed an internal team of engineers, biologists and other natural resource scientists to implement the mitigation in the field.

The implementation teams, with the support of the IID Water Department's operation and maintenance group (O&M), developed an adaptive management program that allows for refinements to the mitigation as necessary. The inclusion of the implementation team members that have permit enforcement authority provides a relatively flexible and responsive process for interpreting and refining the real world mitigation activities.

The IID-SDCWA transfer mitigation plan calls for the enhancement, preservation, creation and management of various habitat types in the covered areas. These include vegetation communities in the channels of the irrigation infrastructure, desert habitat along the Valley's perimeter canals and Salton Sea shoreline strand habitat. The mitigation effort is daunting because it includes a large number of covered species that span numerous species guilds. The coverage area is extensive. While the farming area may appear homogenous based on the predominance of agricultural land use, the cropping patterns are very fluid and the various crops provide significantly different wildlife habitat values. Additionally, the Valley has numerous diverse habitat elements interspersed and juxtapostioned within the agricultural matrix that modifies the otherwise monotypic elements of the Valley. One of the first challenges of the mitigation plan was to evaluate the various habitats individually and as a large landscape system, and develop correlations between species use and vegetation communities.

As part of that evaluation process, extensive studies on habitat and wildlife populations were conducted. Five years of vegetation and wildlife surveys were completed to establish the presence of species within the Valley, identify distribution and usage patterns, and establish a baseline framework for habitat modeling and determination of management practices. Studies on specific at-risk species, including the Western burrowing owl and the desert pupfish were also implemented to evaluate population trends and distribution. A three-year study on water quality was also conducted that evaluated several water quality parameters that might inform future management of the aquatic habitat. This information, along with previous information on species distribution and population trends, helps in the development of a Valley-wide database and inventory of species and habitat.

After the quantification and evaluation of habitat functional values of the drain vegetation was completed, IID implemented Phase I of the managed marsh habitat mitigation. As designed, the 359-acre Phase I provides enhanced habitat value by intermixing open water, dense aquatic emergent vegetation, mesic herbaceous areas and woody vegetation in one area; thus reducing the loss of habitat value from edge effect. Phase I, completed in 2009, will serve as a living laboratory for the design of the next two phases. When completed, the managed marsh complex will include 959 acres of aquatic habitat.

IID also modified its O&M to incorporate several water transfer mitigation measures. An extensive burrowing owl burrow avoidance program has been implemented that required IID to revamp drain maintenance. The avoidance process includes marking of potential burrows prior to the maintenance activity. An extensive training program, including flash cards for species identification and a workers guide to mitigation measures, was developed and implemented to provide the IID O&M team with instruction on proper avoidance and mitigation measures. Annual training and periodic refresher courses are provided. The training program includes a worker input process that has resulted in several improvements to the logistics of the implementation process. The burrowing owl mitigation program also includes an artificial burrow creation effort and a public outreach program.

The O&M program was also modified to accommodate measures to avoid or minimize impacts to the desert pupfish populations. These measures included the development and implementation of a pupfish trapping protocol to identify distribution patterns and provide qualitative information for determining populations. IID also completed the construction of a desert pupfish refugium.

Along with the habitat mitigation, IID in cooperation with the California Air Resources Board, Department of Water Resources, Torres-Martinez Desert Cahuilla tribe and the Salton Sea Ecosystem Restoration Program, developed the Salton Sea Regional air monitoring system, a six station meteorological and particulate matter air quality monitoring system located around the Salton Sea. IID is continuing with the development of a playa exposure model designed to qualitatively estimate the emissivity of the playa areas that will be exposed as Salton Sea elevations decline. In addition, IID has implemented several dust control pilot projects to evaluate the efficacy of various playa treatment measures.

Socioeconomic Mitigation

As part of the IID-SDCWA transfer, the IID took on the task of distributing $50 million of the socioeconomic mitigation funds to certain stakeholders impacted by the fallowing. The current mitigation plan requires that stakeholders believing they are impacted submit claims and the IID Board decides annually which applicants actually get money. One-third of the socio-economic mitigation funds are reserved to fund more broad reaching programs rather than paid directly to stakeholders. To date, job training classes, that include clerical, machinist, home care, and nurse aids have been paid for with IID-SDCWA transfer funds. Other Valley-based economic stimulus programs are also under evaluation and consideration.

Equitable Distribution Program

One key component of the settlement agreements enabling the IID-SDCWA transfer is that IID's Colorado River entitlement is now capped. A team of economists and engineering experts evaluated and recommend an inter-district apportionment to essentially move the cap at the river to individual water users when needed to limit IID use to the capped volume. The approach was to interview water users, then set up a working group of water users district-wide to develop a recommendation to the IID Board of Directors for an Equitable Distribution Program. Several approaches were considered, but based on stakeholder preference, a transition approach was recommended starting with historic water use and moving to a prorated apportionment based on farmed acres, including the allowance for a forecasted rate of growth in municipal and industrial water use. The recommendation also included a proposal that apportionment be implemented only in years when there is a probability of fifty one percent or greater that the forecasted water supply for the following year will be less than the forecasted demand, resulting in a Supply Demand Imbalance (SDI) year. Experts developed forecasting tools to predict an SDI year for the IID operations staff and each year by October 1st, the SDI for next year is predicted, and the IID Board of Directors decides whether to implement apportionment for the following year. The Equitable Distribution Plan, with minor modifications, was adopted by the IID Board of Directors.

Conservation Water Accounting

A team of engineers and computer programmers developed a new computer based transfer water accounting system that would integrate with the existing IID water accounting system, and include the verification of conserved water and the inter-district equitable distribution program. Because of the complexity of the conservation program, additional accounting tools were developed for water operators to help them become more effective in their water operations decisions. Accounting for the water volumes generated by the fifteen year fallowing program and the efficiency conservation program required the tracking of water to various purposes as well as understanding system losses associated with conserved and delivered water to IID customers. The resulting accounting systems provide flexibility to the operators and is composed of a complex system of computerized database interrelated tables, views, procedures, functions, forms, reports and programming packages. The transfer water accounting system accounts for each participating field in the program, as well as the system conservation, as water diverted at the Colorado River. Final reports are generated for the SWRCB and the BOR.

A water ordering system and water order decision support system were developed and implemented for the water coordinators to assist them in meeting water customer demands. One of the keys to the integration of these systems was to assist water operators in determining available capacities within the delivery system to accommodate additional water orders. When capacity is not available, or the supply is less than the sum of the water orders, the system recommends which water orders can be carried over to another day. These systems include tracking water to each farm field, crop being irrigated, and municipal and industrial users for conservation verification. These systems were also set up to accommodate intradistrict allocation needed to implement the Equitable Distribution Program, and a new billing system.

System-wide water data is collected by an upgraded Supervisory Control and Data Acquisition (SCADA) system. That data is automatically transferred to a data warehouse, the Water Information System, where the data is quality controlled and stored in tables for automatic generation of reports and access by decision support systems. IID staff have been assigned to review the quality controlled data reports to determine if specific measurement locations within the water delivery system require maintenance, repair, or are not meeting conservation targets set each year by the conservation verification system. The Quality Control System runs automatically one or more times each day and produces reports for IID staff and the verification system. Once staff approve the provisional data, the system finalizes any changes and the data is then stored permanently.

A main canals decision support system (MCDSS) was developed and implemented. It is an integrated collection of decision support tools designed to provide decision and accounting assistance to the main canal operations. The decision support system (DSS) decisions are of two types: flow scheduling and system operations. The principal scheduling decisions involve determining the master water order for IID from the Colorado River and allocation of tomorrow's water supply, all with the consideration of the system conservation. One of the keys to this system is more efficient operations and less carryover of water orders during water supply deficits. The DSS format allows "what if" operations scenario analysis allowing the water operators to make the best decisions for efficient operations. Once operations decisions are made, main canal sales area breakdown reports are produced for each of the zanjero lateral runs.

Water Conservation Program

Although there was feasibility level engineering and economics done during the negotiations of the IID-SDCWA transfer, all of this work was based on the conservation experience of a past transfer. As a result, the first step in the IID-SDCWA transfer was to assemble a team of experts to develop a "Definite Plan" to provide a roadmap that identifies the mix of on-farm actions, incentive packages and delivery system improvements that can collectively conserve the water to be transferred and do so in a way that assures the actions proposed are cost effective, implementable, verifiable and acceptable to growers, IID, and others with a stake in the transfer program.

The IID-SDCWA transfer is part of a complex package of other settlement agreements[7], and the first task to develop the Definite Plan was to understand all the agreement terms. The technical team, working with the negotiators and the legal team, identified the following critical terms:

- The water to be transferred to SDCWA must be produced by efficiency conservation, not by land fallowing or other means[8].
- IID must meet or exceed the conserved water transfer schedule (Figure 5). Efficiency-created water begins in 2008 when just 4 kaf is to be transferred, and gradually increase to the ultimate transfer amount of 303 kafy by 2026 (200 kafy to SDCWA, 100 kafy to others).
- Of the 303 kafy to be transferred, no less than 130 kafy must be produced by on-farm water savings. Thus, at program build out in 2026, on-farm efficiency conservation savings could range from 130 kafy to 303 kafy, and distribution system savings could range from zero to 173 kafy.
- Participation in the on-farm conservation program by IID landowners and growers must be voluntary. Furthermore, landowners and growers must be allowed to choose their own means of conserving water on-farm.
- Water savings, both on-farm and in the delivery system, must be verifiable.

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[7]IID. 2007. Imperial Irrigation District description of the Quantification Settlement Agreement available on-line. http://www.iid.com/Water/QSAWaterTransfer

[8]Land fallowing is allowed for a temporary period to generate water for transfer and for Salton Sea mitigation. Fallowing began in 2003 and must end by not later than 2017. Due to concerns about negative economic impacts, there is strong interest in the Imperial Valley to end fallowing as early as possible.

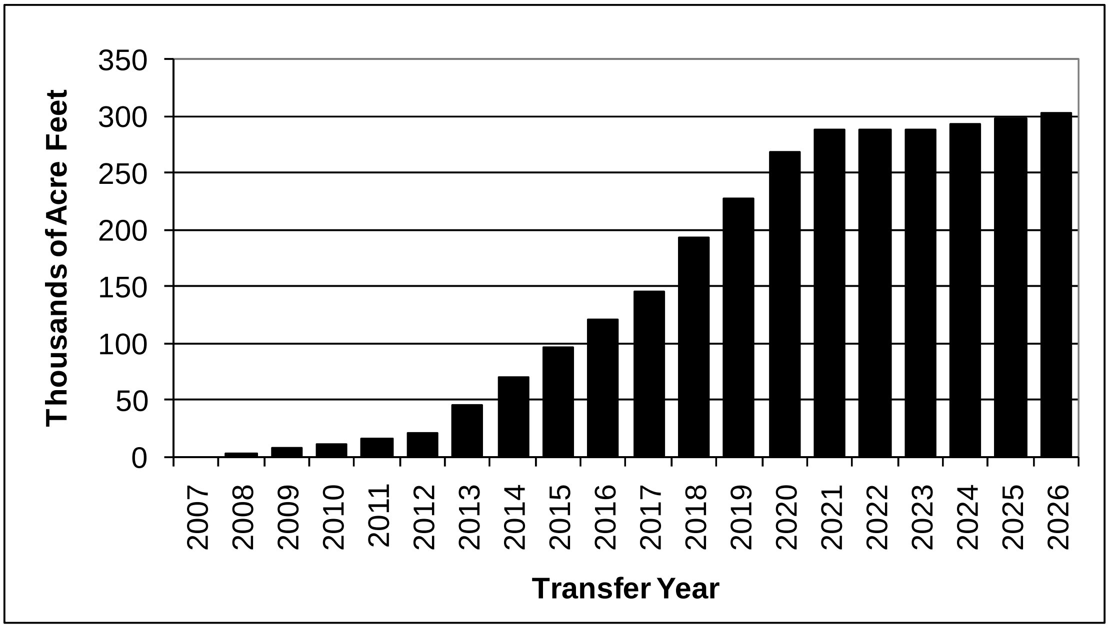

Figure 5. QSA Transfer Schedule.

In addition to the agreement requirements, IID established a number of criteria, or guiding principles, for development of the Definite Plan to ensure that it would be effective and implementable:

- The Definite Plan must be technically viable. It must rely on conservation measures and technologies that are proven and currently available, while allowing for the probability that new technologies will be developed during the long term of the transfers.
- The on-farm and delivery system conservation programs must be integrated, recognizing that each program will influence the performance of the other.
- Implementing the conservation program involves risk due to the uncertainty in the costs and water savings associated with implementing conservation measures. This risk must be fairly shared and adequately compensated to attract farmers to participate.
- The overall conservation program must be accomplished within available transfer revenue and allow for uncertainty in actual cost and performance. Contingencies should be provided to deal with these uncertainties.

The Definite Plan was participatory in order to tap into the experience and views of IID staff, landowners and especially growers, who will be the ones responsible for implementing on-farm conservation. Additionally, the process was technically rigorous to ensure that the on-farm and distribution system components would work together, and would achieve the targeted program savings at least cost. All available data was considered.

Prior to integrating the results in alternatives analysis, separate on-farm and delivery system studies were undertaken. Data analysis was facilitated by the development of a decision support system (IIDSS) that included several computer models designed to analyze the effects of implementing a voluntary on-farm conservation program on cost, and conservation and delivery system performance. The IIDSS and other foundational studies provided basic conservation data and allowed the analysis of a broad range of alternatives to arrive at final recommendations.

The first task in the development of the Definite Plan was to complete a detailed water balance to establish the total potential on-farm and delivery system water savings within IID. The water balance confirmed that tailwater, which occurs almost entirely from surface-irrigated fields, is the primary target of the on-farm water conservation program. The water balance also confirmed that canal seepage and lateral spillage were the two primary conservation targets within the IID delivery system.

Next a broad range of on-farm and system conservation measures were examined. The on-farm conservation measures represented the types of actions farmers might use in a voluntary program. They ranged from management actions such as irrigation scheduling and improved irrigation event management to converting to other types of irrigation methods (e.g., basin, drip or sprinkler). They also included measures that capture and reuse tailwater. Once the various conservation measures were identified, their adaptability to various combinations of IID crops and soils was defined and costs developed relative to the field and crop, with field size and crop type being the main keys. All costs and estimated savings were included in the analysis.

Within each on-farm approach, many formulations of payment rates, water use baselines, and other payment parameters were evaluated. An analytical tool called the Demand Generator was developed to simulate the adoption of on-farm conservation measures under different incentive approaches. The Demand Generator evaluated the costs, payments, and other benefits that each field and crop-season in IID's historical database would face under an incentive approach, and selected the grower's preferred decision based on highest expected net return.

After rigorous analysis, the system conservation measures most likely to be used included the following:

- Canal seepage interception
- Real time, remote monitoring of lateral spillage and other system conditions, with the information provided to system operators (zanjeros) in the field
- "Zanjero" (lateral-level) regulating reservoirs, which put regulating capacity closer to the points of water delivery and under the zanjero's control, thereby enabling a closer match between water supply and demand
- Main canal reservoirs to enable more flexible delivery of water into lateral headings, as requested by the operators
- System interconnections and interceptor canals, which collect and reuse lateral spillage, some by gravity, others by pumping
- Upgraded spill structures
- Non-leak lateral check gates

Once the conservation potentials and the possible on-farm and system conservation measures determined, the next step was to create alternative conservation program scenarios and evaluate those scenarios for cost effectiveness and ability to create the water as needed by the conservation ramp-up schedule. Building blocks for alternatives formulation were the promising, incentive-driven approaches for achieving on-farm water conservation, and the set of delivery system projects for reducing losses and improving delivery flexibility. Alternatives were defined primarily by the volumes of water targeted for on-farm and system savings, respectively, to provide the 303 kafy of annual conservation savings at program buildout. Seven conservation mix alternatives were formed, ranging from a "maximum on-farm" alternative designed to produce 280 kaf from on-farm conservation and 23 kaf from system savings, to a "maximum delivery system" alternative designed to produce 158.8 kaf on-farm and 144.2 kaf from system savings. Cost effectiveness was determined by the amount of economic "head room" between anticipated conservation system cost and available revenue.

Over recent years, IID has been developing a set of analytic tools to enable evaluation of its water delivery system. The IIDSS was developed to support evaluation of environmental effects, especially changes to flows and water quality in IID's canals and drains that could be expected under a broad range of alternative water conservation programs. IIDSS was updated and expanded for the Definite Plan and used to evaluate and compare the seven most likely alternatives. Figure 6 presents the range of costs for the alternatives selected for final analysis. The spread between the upper and lower bounds represents the range of on-farm incentives examined with the lower costs representing payment for conservation measures and the upper bound representing a hybrid incentive structure. The costs shown include costs for improved measurement at all delivery turnouts for verification and to administer the program. Analysis of the alternatives suggested an optimal mix of between roughly 180 kaf to 210 kaf of on-farm water savings combined with 93 kaf to 123 kaf of delivery system conservation savings. The range was necessary to cover uncertainty in conservation performance of the various measures. This range recognizes the need for some financial "head room" to allow for contingencies beyond those included specifically in the analysis.

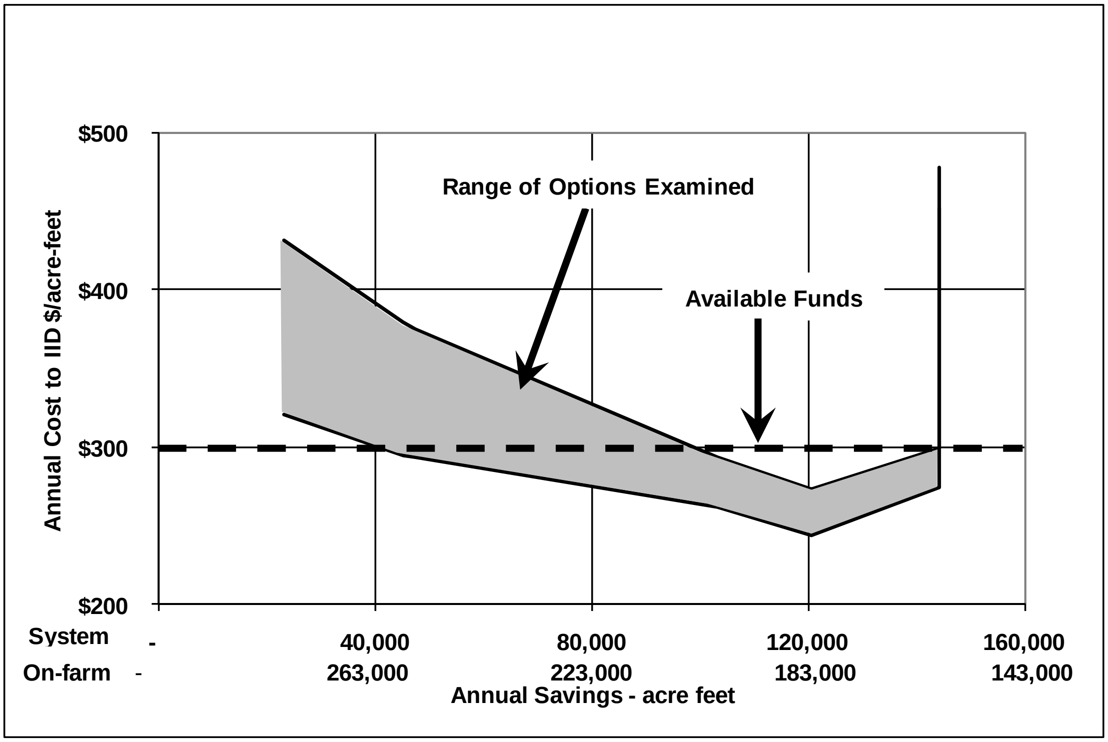

Figure 6. Range of conservation alternatives to generate 303,000 acre-feet of conservation savings annually.

The recommended program includes the following elements:

- An on-farm incentive program with adequate incentive above farmer cost to induce participation with savings of from 180 kaf to 210 kaf
- A canal seepage interception system capturing between 40 kaf and 45 kaf (this system is presently under construction)
- A delivery system improvement plan saving from 48 kaf to 78 kaf, providing improved on-farm delivery with the following elements:
  - 1,600 af of additional main system storage
  - Up to 27 lateral reservoirs with 665 af of total capacity
  - Major SCADA system upgrade with remote monitoring and control capabilities in the hands of canal operators
  - Automated flow-control lateral headings
  - Remotely monitored spill measurement at all spill points
  - Selected low-cost lateral inter-ties for improved lateral operation
  - Installation of non-leak gates at key locations to reduce lateral spill
  - SCADA equipped flow measurement and control at each delivery gate

CONSEQUENCES AND REMAINING CHALLENGES

As of mid-2011, the IID-SDCWA conserved water transfer and related activities has progressed through:

- An outline concept of basic terms in 1997;

- Environmental review, approval and permits under CEQA, NEPA and state and federal endangered species acts;

- Weeks of evidentiary hearings before the SWRCB in 2002 and a transfer approval order conditioned on specified environmental mitigation;

- A set of contractual agreements totaling hundreds of pages that includes specific and detailed volume, transfer revenue, mitigation and settlement provisions approved by the contracting parties in 2003;

- Transfer ramp-up from 10 kaf in 2003 to 96 kaf in 2011, including 16 kaf of system efficiency as a source;

- Development of a Definite Plan for producing the full contractual volume of conserved water for transfer, 200 kafy to SDCWA and 103 kafy to others, that accommodates contract requirements for ramp up, method of conservation, available revenue and flexibility to accommodate the long term aspects of the agreements;

- Implementation of an environmental mitigation and monitoring plan premised on an adaptive management approach to changing environmental conditions and a socio-economic mitigation plan that shares mitigation payments among directly impacted persons and compensates indirectly affected areas or populations through economic stimulus and job training programs.

Despite these accomplishments, many challenges remain to be overcome. The truism "you can't please all the people all the time"—coupled with the political sensitivities of the transfer and efforts by certain groups to gain influence or leverage—has resulted in significant litigation and other types of efforts to stop, slow or change many aspects of the transfer. Although to date, all of these efforts have failed to disrupt the transfer, careful planning and implementation remain the best defense to these challenges.

The IID-SDCWA conserved water transfer and its related activities have in fact created significant benefits for the Imperial Valley and coastal urban Southern California. The goals of better water management by IID, environmental protection, and the creation of new supplies for junior California Colorado River right holders is being accomplished pursuant to a consensual arrangement that benefits all affected parties.

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REORDERING AGRICULTURAL ACTIVITIES IN THE MEXICALI VALLEY AS RESPONSE TO 2010 EARTHQUAKE

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ABSTRACT

Agricultural activities in the Mexicali Valley of Baja California, Mexico were reordered territorially as a consequence of the April 4th, 2010 earthquake, which registered a magnitude of 7.2 on the Richter scale. The National Water Commission (CONAGUA) reported severe damages in the hydraulic infrastructure and soil in an area of 28,009 hectares that will not be able to be cultivated to full capacity for the next three years and are mainly located in irrigation modules (agricultural water user associations) #10, 11 and 12 in the second of the Mexicali Valley's three irrigation units. As a response to this situation, many of the farmers who own land in the affected zones have changed their water rights to other areas in the Mexicali Valley, have rented their water rights to other farmers that own land in non-affected areas, or have enrolled in a program implemented by CONAGUA to stop using their irrigation rights in exchange for compensation. Changes in water usage intensity were analyzed in the three Mexicali Valley irrigation units by comparing the water volumes used or transferred prior to the earthquake (from 2005 to 2009) to volumes used or transferred after the earthquake. The extraction water from the aquifer in the Mexicali Valley stopped entirely and has been substituted with surface water from the Colorado River that was not used in affected areas.

INTRODUCTION

The Mexicali Valley in Baja California and San Luis Rio Colorado Valley in Sonora, Mexico, receives water from Irrigation District 014, Colorado River, which is divided for water management into 22 agricultural water user associations, referred to as "irrigation modules" (Figure 1). Three of the modules are located in the state of Sonora and the rest (19) in Baja California (BAR SC, 2009). Irrigation District 014 has an agricultural area of 208,223 hectares with water rights for the farming of one crop per year. There are 15,894 registered agricultural users distributed according to the water supply source: 11,205

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users receive surface water to irrigate an area of 137,235 hectares; 3,208 users of federal wells have an area of 48,480 hectares; and 1,409 users of private wells irrigate an area of 22,507 hectares (BAR SC, 2009).

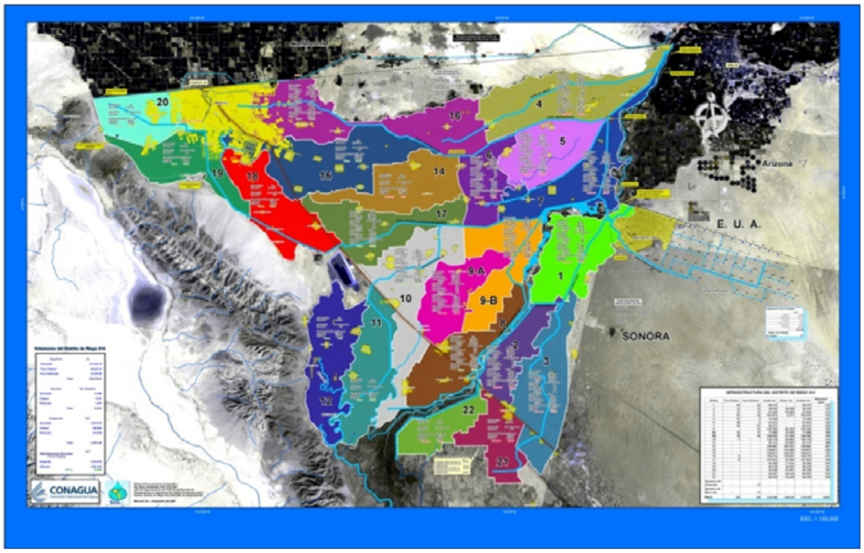

Figure 1. Irrigation District 014, Colorado River (CONAGUA, 2010)

Irrigation District 014, Colorado River receives an annual volume of 2,748 MCM. Of that volume, 1,850 MCM are established in the treaty between the United States of America and the United Mexican States relating to the utilization of the waters of the Colorado, Tijuana, and Rio Grande (Rio Bravo) rivers; the remaining 897 MCM come from groundwater extracted with 725 deep wells (BAR SC, 2009).

For the distribution and use of water there is a large public hydraulic infrastructure composed of the following:

- Major headworks operated by the National Water Commission (CONAGUA):
  - Jose Maria Morelos diversion dam on the Colorado River
  - Sanchez Mejorada canal
- A main canal distribution system operated by a Limited Liability Society formed by agricultural water user associations, with a total of 293 km, 86 of which are not lined:
  - Reforma canal
  - Revolucion canal
  - Independencia canal
  - Alimentador del Sur canal
- Secondary canals operated by agricultural water user associations (modules) and amounting to 2,123 km, of which 426 are not lined (BAR SC, 2009)

For the extraction of groundwater, Irrigation District 014 has 487 federal wells. Of those, 425 are located in Mexicali Valley and in the San Luis Rio Colorado Valley. These wells are leased to users through the Limited Liability Association, which provides their operation and maintenance. Sixty-two wells are located in Mesa Arenosa in San Luis, Rio Colorado, Sonora and are operated by the Irrigation District. Additional structures include 29 pumping plants and 2,683 km of operating roads in the well and canal network, as well as 220 private wells, which are operated and maintained by their owners. The drainage system in the Irrigation District has 1,683 km of main and secondary drains, and 4,200 hectares with pipe drainage (BAR SC, 2009).

SEISMIC ACTIVITY IN THE MEXICALI VALLEY

The Mexicali Valley in Baja California, Mexico, is located in an area with intense seismic activity. The San Andreas Fault system has a length of approximately 1,286 km and passes through the states of California (USA) and Baja California (Mexico). The system is composed of numerous faults or segments. In the southern area of interest, the dominant faults are the San Jacinto, Imperial and Cerro Prieto (Chavez, et al., 1982).

The dispersion centers in the Mexicali-Imperial Valley, such as Cerro Prieto and Brawley, are connected through active transform faults known as Brawley, Imperial and Cerro Prieto, which generate the bulk of the seismic activity that characterizes this region. The activity is mostly microseismic, but is also manifested with sequences of precursor earthquakes, main events and aftershocks, or as swarm forms (González-García, 1986; Frez y Frías Camacho, 1998).

During the last decades, the main faults of Imperial and Cerro Prieto have generated earthquakes with magnitudes between 6.1 and 7.1 on the Richter Scale, that have damaged the hydraulic infrastructure and agricultural lands in the Mexicali valley. Among the more important earthquakes are the ones that took place May 18, 1940 and October 15, 1979, with magnitudes of 7.1 and 6.6 respectively and associated to the Imperial fault (Chavez, et al. 1982); and on June 8, 1980 with a magnitude of 6.1 generated in the Cerro Prieto fault (Frez y Gonzalez, 1989, Wong, et al. 1997). This last one resulted in the rupture of the Nuevo Delta canal near the Cerro Prieto Geothermic Field.

On December 30, 2009, an earthquake of 5.8 degrees ruptured the Reforma Main Canal. Damage included displaced concrete panels, plus fissures in protective borders and canal roads along a length of 1.2 km. This canal is the most important of the surface water distribution system in the Mexicali Valley and carries water for agricultural irrigation, Mexicali Valley towns and 30% of human use in the city of Mexicali. It also feeds the aqueduct that supplies water to the coastal zone of Baja California, including the cities of Tijuana and Tecate (CONAGUA, 2009).

On April 4, 2010, the Mexicali Valley was struck by a magnitude 7.2 earthquake that lasted 89 seconds. The earthquake was called El Mayor-Cucapah, and took place at 15:40 local time in Baja California. Its epicenter was pinpointed in the western margin of the Mexicali Valley, in an area where the Mayor and Cucapah mountains converge, about 40 km south of Mexicali (Munguia, et. al. 2010).

This earthquake brought damages to the hydraulic infrastructure that provides water for crop irrigation and water to the Mexicali Valley towns. Also, more than 75,000 hectares of different crops were affected, mainly wheat with an area of 43,609 ha, alfalfa with 11,146 ha, cotton with 194 ha (Figure 2) and 300 hectares of vegetables (SEFOA, 2010; SAGARPA, 2010). In an assessment of the damages to agricultural lands, CONAGUA found damages in 57,035 hectares. Most of the damage was the result of the upwelling of water due to liquefaction and flooding caused by the rupture of irrigation canals and soil cracking (CONAGUA, 2010).

Figure 2. Cotton crop damages, Irrigation Module 21

According to information from Irrigation District 014, in an area of 208,525 hectares where damages were assessed, few damages were recorded in 106,987 hectares, medium damages were apparent in 73,529 hectares, and high damages occurred in 28,009 hectares. The highly damaged fields require special handling, as they were the most affected (CONAGUA 2010). The irrigation modules with most damages to their infrastructure and agricultural lands were modules 10, 11, 12 and 21.

The main damages to the hydraulic and drainage system occurred throughout 633 km of canals. Of those, 56.3 km belonged to the main Reforma, Nuevo Delta and Revolucion canals (Figure 3), and the remaining 576.6 km belonged to secondary canals (Figure 4). The drainage system suffered 274 km of damages. Sixty-eight km of drains will be repaired, and the rest (205 km) will be rebuilt (CONAGUA, 2010).

Table 1. Types of damage to agricultural lands (CONAGUA, 2010)

Type of damage	**Level of damage (ha)**			**Assessed surface (ha)**
	High	**Medium**	**Low**	
Lack of irrigation water	24,083	16,705	3,285	44,073
Uneven land	18,666	12,667	1,719	33,052
Flooding caused by upwelling	9,679	9,122	3,205	22,007
Land cracking	8,712	7,600	1,713	18,024
Flooding caused by canal rupture	810	305	58	1,173
Total 26,106		**18,390**	**12,539**	**57,035**

Figure 3. Concrete lined canal damages

Figure 4. Canal bottom cracking

NORMAL SUPPLY AND DEMAND OF WATER IN THE MEXICALI VALLEY

In normal annual irrigation cycles (Oct. 1 - Sept. 31), irrigation modules 8, 10, 11, 12, 15, 16, 17, 18, 19 and 20 participate in an exchange program where modules that do not require the guaranteed supplied water in its entirety sell the excess water to modules that need more water than the guaranteed supplied volume. Through these exchanges, an average yearly cycle volume in the neighborhood of 143 MCM was sold over the 4 years preceding the earthquake (Table 2). Transfer and sale of water is done through a water bank, which is an organization created and operated by water users to negotiate between irrigation modules.

Table 2. Yearly volume supplied by the irrigation modules through the water bank (CONAGUA, 2011a)

Irrigation module	Supplied water volume per agricultural cycle (MCM)				
	2005-2006	2006-2007	2007-2008	2008-2009	Average
8	0.0	6.7	0.0	0.0	1.7
10	12.3	11.3	8.6	3.0	8.8
11	8.2	10.4	10.7	8.5	9.5
12	4.1	8.2	10.0	7.0	7.3
15	24.6	18.1	28.2	26.8	24.4
16	9.0	7.5	10.7	8.5	8.9
17	4.9	9.5	6.1	3.5	6.0
18	20.5	29.6	33.5	27.6	27.8
19	23.0	32.2	35.1	30.0	30.1
20	8.2	20.7	21.2	23.0	18.3
TOTAL	**114.8**	**154.0**	**164.2**	**138.0**	**142.7**

Modules 1, 2, 3, 4, 5, 6, 7, 9A, 21 and 22, as well as operating bodies such as Public Services Estate Commission, bought an average volume of 134.2 MCM of water in addition to their yearly guaranteed supplied water prior to the earthquake (Table 3). This additional water came from modules 8, 10, 11, 12, 15, 16, 17, 18, 19 and 20, which generally did not use their yearly guaranteed water supply, given their geographic location near the city of Mexicali or their low quality soils (which results in a lower crop intensity). Water modules that buy water are the ones located in higher quality soils in the Mexicali Valley and dedicated to higher crop intensity.

Table 3. Yearly volume acquired by irrigation modules through the water bank (CONAGUA, 2011a)

Irrigation Module	Water volume acquired per agricultural cycle (MCM)				
	2005-2006	2006-2007	2007-2008	2008-2009	Average
1	22.3	28.9	30.7	20.8	25.7
2	1.7	12.1	11.1	7.5	8.1
3	0.9	14.8	18.8	6.6	10.3
4	11.4	8.9	4.1	0.1	6.1
5	7.7	19.9	16.6	7.4	12.9
6	8.6	13.6	12.9	5.5	10.2
7	16.2	19.1	18.1	5.7	14.8
9A	22.5	0.0	20.6	15.0	14.5
9B	8.9	8.0	7.3	4.6	7.2
14	2.2	5.9	4.2	4.9	4.3
21 y FL	6.9	7.1	6.3	0.2	5.1
22	5.5	15.7	13.4	15.7	12.6
FLC[1]	0.0	0.0	0.0	9.7	2.4
OO[2]	6.0	16.3	16.4	16.4	13.8
TOTALS	114.8	154.0	164.2	103.7	134.2

[1] Outside the Irrigation District boundaries
[2] Public Services Estate Commission

CHANGES TO USAGE OF WATER IN THE MEXICAL VALLEY

As a result of the April 4, 2010 earthquake, water usage for agricultural activity in the Mexicali Valley was redistributed due to the damages suffered in the hydraulic infrastructure for water distribution. The most affected areas were in modules 10, 11 and 12, which together comprise an area of 38,798 hectares with irrigation rights, containing 3,205 agricultural producers with 378 MCM leased to irrigate that surface.

In the four annual cycles prior to the earthquake, irrigation modules 10, 11 and 12 had 20.5 MCM of water at their disposal to negotiate through the water bank, and for that same period module 21 received additional volumes that averaged 5.1 MCM annually (Table 3). After the earthquake, modules 10, 11 and 12 were unable to use their assigned water for the 2009-2010 cycle, so those three modules ceded to the water bank 57.6 MCM, increasing their combined transferred volume by 181%. In percentile terms, the module that transferred the most water was 11, which transferred 410% of the volume it usually makes available. Conversely, module 21, which received additional water volumes in the years prior to the earthquake, did not receive any after the seismic event.

For the 2010-2011 water season up to the month of March, the volume transferred from modules 10, 11, and 12 has totaled 22.6 MCM, which represents 10% more water than normal. For module 12, the transferred water volume is still 45% higher than normal (Table 4). This is because more farmers enrolled in a program implemented by CONAGUA to stop using their irrigation rights in lands that will not to be able to be cultivated for the next three years in exchange for an aid of 7,000 pesos per ha per yearly cycle for agricultural fields that will not use irrigation water.

Table 4. Water volumes negotiated through the water bank (MCM year[1]).

Irrigation module	Average 2005 to 2009 (MCM)	**Agricultural Cycle**			
		2009-2010		2010-2011 (up to March)	
		MCM	%[1]	MCM	%[1]
10	5.2	12.0	131	3.0	-42
11	3.9	20.0	410	3.1	-20
12	11.4	25.6	125	16.5	45
Total 20.5		**57.6**	**181**	**22.601**	**10**

[1] Percentage compared to average volume for agricultural cycles 2005 to 2009

During the 2009-2010 agricultural cycle, a portion of the water that was not used for crop irrigation in modules 10, 11 and 12 was moved to the canal system in the federal well area, intended to diminish the water extraction from the aquifer and out of usage canals that recharge the aquifer (Figure 5), among others (CONAGUA 2011b). This resulted in a volume of 22.3 MCM (18,056 acre-feet) being used for crop irrigation during the 2009-2010 season, less water from the aquifer than in 2005-2009. For 2010-2011, even though it is a partial advance of the agricultural cycle (October to March) and cannot be compared with the 2005-2009 cycle, it can give us a general idea of the behavior in the negotiation of water through the bank water. This can be seen in the availability of water for sale in irrigation module 12, where there was 45 percent more water for sale in 2010-2011 than in 2005 -2009.

The increased volumes of water sold through the bank of water in the irrigation modules 10, 11 and 12, was due to the damages that occurred in the system of channels for water conveyance during the earthquake, and there is no ability to drive the water needed for crops in these modules. Therefore, the water rights that the National Water Commission obtained through their exchange program cannot be used in irrigation modules 10, 11 and 12 over the next three years due to damage to canals and farmland. Likewise, the National Water Commission has acquired during the 2010-2011 cycle a water volume of 118 MCM (95,968 acre-foot) with an area of 9,994 hectares of agricultural land not cultivated in these modules (Table 5). For the 2011-2012 cycle, CONAGUA estimates that the program serves 943 users with an area of 13,358 hectares and a water volume of 158 MCM (126,172 acre-foot).

Table 5. Exchange program of water rights from agricultural user to National Water Commission (CONAGUA), 2010-2011 cycle.

Irrigation module	Total lands with water rights (ha)	Lands in the Exchange Program of water rights (ha)	Lands in the Exchange Program of water rights (%)	Water Volume (MCM)[1]	Economic compensation (Pesos)[2]
10	12360	2052	16.6	24.3	24,000,000
11	9140	4430	48.5	52.4	39,000,000
12	9500	3512	37.0	41.6	33,000,000
Total	31000	9994	32.2	118.3	96,000,000

[1]11,840 cubic meters per hectare of water rights (9.6 acre-foot per hectare)
[2]$7,000 pesos per hectare

Figure 5. Old North Canal, May 1 2010

CONCLUSIONS

1. Main damages to the hydraulic and drainage system affected 633 km of canals. Of those, 56.3 km were the main canals Reforma, Nuevo Delta and Revolucion. The remaining 576.6 km of damages affected secondary canals. The drainage system damages occurred on 274 km; 69 km of the drainage system will be rehabilitated by repair and the remaining 205 km will be rebuilt.
2. The most affected irrigation modules were 10, 11, 12 and 21, which together total an area of 38,798 hectares with irrigation rights, with 3,052 agricultural producers. These modules were typically allocated 387.2 MCM annually for crop irrigation.
3. Irrigation modules 10, 11 and 12 were unable to use the water at their disposal for the 2009-2010 cycle, so their excess water was made available to the water bank. For

2010, a volume of 57.6 MCM was allocated to the water bank from these three modules, amounting to an increase of 181% from previous years. The most diverted water came from module 11, which transferred 410% more water than usual.

4. During the 2009-2010 agricultural year, less water was used from the aquifer for crop irrigation compared to 2005-2009 with a volume of 22.3 MCM (18,056 acre-feet). These water volumes were instead supplied by surface water coming from the Colorado River that was not used by the seismic-affected areas.
5. National Water Commission has acquired during the 2010-2011 cycle water volume of 118 MCM (95,968 acre-foot) with an area of 9,994 hectares of agricultural land not cultivated in the irrigation modules 10, 11 and 12.
6. For the 2011-2012 cycle, the CONAGUA estimates that the program serves 943 users with an area of 13,358 hectares and the water volume of 158 MCM (126,172 acre-foot).

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INSTITUTIONAL RESPONSE TO NATURAL EVENTS: CASE OF MEXICALI EARTHQUAKE, APRIL 2010

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ABSTRACT

An earthquake lasting 89 seconds occurred in the Mexicali Valley on April 4, 2010, with a registered magnitude of 7.2 on the Richter scale. Among the negative effects caused by this earthquake in the agricultural zone in northwest Mexico, damages to 407 km of irrigation canals and 380 km of open ditches were documented. Soils were affected severely in an area of 26,106 hectares (Ha), with medium damage on 18,390 hectares, and low damage on 12,539 hectares (SEFOA, 2010). Likewise, crops on 57,035 hectares were affected, mainly to fields of wheat, alfalfa, cotton, and vegetables. To solve the negative effects on crops, federal and state governments established four programs: (1) a Strategic Project of Regional Impact to provide aid for wheat, cotton and alfalfa farmers in the Mexicali Valley and San Luis Río Colorado Valley with 100% yield damages; (2) a Strategic Project of regional impact providing aid to wheat farmers with partial yield damages in the Mexicali Valley and San Luis Río Colorado Valley; (3) a Strategic Project of Regional Impact to recover the productive capacity of agricultural land in the Mexicali Valley, B.C. (PRECAPS); and (4) a temporary transfer of water rights, established for fields without irrigation water service access in the agricultural period of autumn-winter 2010-2011. The total investment on those four programs is 370.5 million pesos (US$31.7 million). Additionally, during 2010 1,174.8 million pesos (US$100.6 million) was invested in the infrastructure of the irrigation district, with 3,568 benefited farmers and 180,783 hectares.

INTRODUCTION

The state of Baja California is located in the northwestern region of Mexico; it is located geographically between meridians 117° 06' and 112° 46' west longitude, and parallels 28° 00' and 32° 43' north latitude (CONEPO 1993, cited by Orozco, 2001).

Irrigation District 014 (ID), along the Colorado River, consists of the Mexicali Valley (Baja California), and San Luis Río Colorado Valley (in Sonora state). It has 22

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irrigation modules (water user associations), with between 7,000 to 12,000 hectares per module, and a total area of 207,795 hectares (513,500 acres). Nineteen of the modules are located on the western side of the Colorado River and belong to the Mexicali Valley; 3 are located in the San Luis Río Colorado Valley. ID has 1,850 km of lined canals for irrigation purposes and 1,378 km of roads which run along the canals to allow traffic, maintenance and infrastructure repair. The drainage system has 1,600 km of main and secondary drains.

The district has a total volume of 2,748 million of cubic meters (MCM) (3.04 million AF) of water per year; 1,850 MCM are established in the "Treaty regarding distribution of international waters, Tijuana, Colorado and Bravo River" signed February 03 1944 in the city of Washington, District of Columbia, by the governments of United States and Mexico, and the remaining 897 MCM comes from underground water extracted from 725 deep wells.

EARTHQUAKE DAMAGE AND ACTIONS TAKEN

Earthquake Damage

An earthquake was registered in the Mexicali Valley on April 4th 2010, with a magnitude of 7.2 on the Richter scale, lasting 89 seconds (Figure 1).

Figure 1. Earthquake's Location, Magnitude 7.2 Richter Scale (CISN, 2010)

Due to this event, 57,035 hectares (Ha) of different crops were damaged, mainly wheat with a damaged area of 43,609 hectares, alfalfa with 11,146 hectares, cotton with 1,945 Ha and 335 of vegetables (SEFOA, 2010).

The total area with damage and the types of damage to soils are show in Table 1.

Table 1. Types of Damage to Farm Land (SEFOA, 2010)

Type of damage	High	Medium	Low	Impacted surface (Ha)
Lack of irrigation water	24,083	16,705	3,285	44,073
Unevenness of land	18,666	12,667	1,719	33,052
Water table flooding	9,679	9,122	3,205	22,007
Land cracking	8,712	7,600	1,713	18,024
Flooding by ruptured irrigation canals	810	305	58	1,173
Total area with one or more problem	**26,106**	**18,390**	**12,539**	**57,035**

Figure 2 shows the locations of various intensities of the damages listed in Table 1. The "M" designations on Figure 2 indicate a module (water user association).

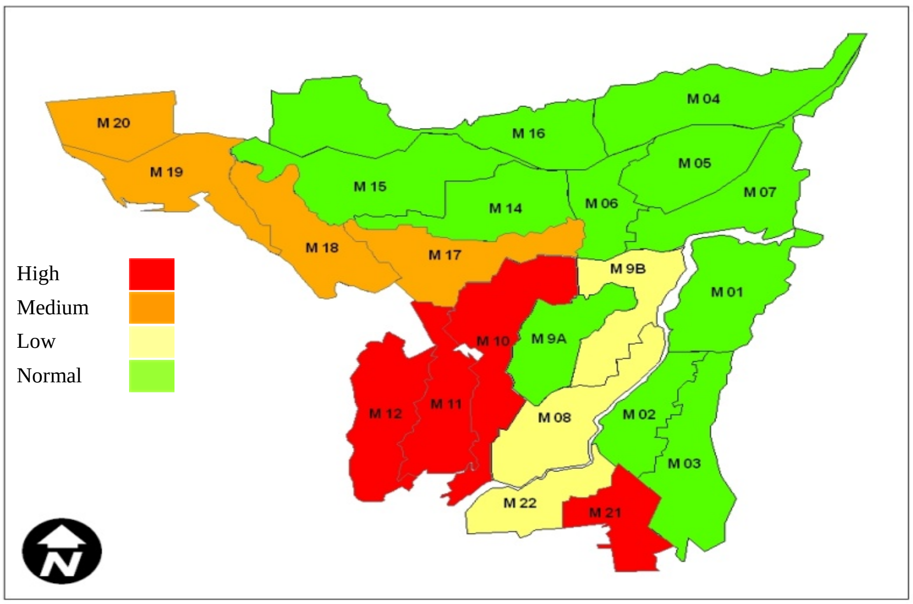

Figure 2. Location of Damages in Irrigation Modules and type of damage (SEFOA, 2010)

Main damages to the hydraulic system and drains were (SEFOA, 2010):
1. 57 km of main irrigation canals; Reforma, Nuevo Delta and Revolución canals.
2. 350 km of secondary canals.
3. 380 km of the drainage system.
4. The total affected farming land area was 57,035 ha.

Due to this situation, the federal and state governments applied many actions and strategies. The primary priority was to continue tending to current crops that were in danger of being lost due to a lack of irrigation water. Action was then taken to make emergency repairs to the damaged infrastructure, an endeavor that would take more than 60 days.

First Actions

Actions taken during the first 60 days (SEFOA, 2010, CONAGUA 2010) included the following:

1. Assembly of teams of agronomists and veterinarians to inspect agricultural lands in an area of 57,035 hectares in the affected zone. The purpose was to assess the damages related to crops, agricultural land, aquifer upwelling, irrigation canal and drainage system collapse.
2. Drawing of a digital map with the locations and classification of the farms previously mentioned.
3. Reestablishment of the water flow for urban use in the two main irrigation canals most affected by the earthquake: the Reforma Canal and the Nuevo Delta Canal. Afterwards, attention turned to the Revolución Canal.
4. Reestablishment of irrigation water in canals with lesser damages.
5. Installation of open ditches to take water to crops, mainly wheat and alfalfa, in areas with collapsed irrigation canals.
6. Drainage of flooded farms, caused by collapsed canals.
7. Sampling of 10,000 hectares of wheat, to detect the disease known as leaf royal line (*Puccinia striiformis*), in farms with excess humidity.
8. Application of a “temporary job” program, which hired workers from the affected areas who lost their jobs, to participate in canal and drain rebuilding duties.
9. Fumigation of drains and lagoons, to prevent insect transmitted diseases.

Actions Taken to Reestablish Productive Activities

Actions taken to reestablish productive activities, which required more than 60 days, were divided into two groups:

1. Restoration of hydraulic infrastructure and drainage.
2. Direct funding to farmers, to settle commitments with financial institutions.

Reconstruction of Hydraulic Infrastructure. The Irrigation District has an insurance policy that covers natural disasters, which considers rebuilding and/or rehabilitating the infrastructure in the main and secondary irrigation canals and drains. The policy covers a land survey to review the topography of each and every one of the main and secondary canals and the drains as well as soil sampling to identify salinity classification.

It was also very important to make additional investments from April to December 2010 to perform urgent hydraulic works, which are presented in Table 2.

Table 2. Investment by the federal and state governments in hydraulic system in the year 2010 (SEFOA 2010)

Concept	Money Invested (million pesos)		Total (million pesos)
	Federal Gov.	State Gov.	
Irrigation canal lining	14.0	8.5	22.5
Conduction water tubing	16.2	1.4	17.6
Subsurface drainage installation	5.5	2.6	8.1
Topography work, project administration, work supervision, studies and agreements	51.3	0.0	51.3
Rebuilding of irrigation infrastructure for 180,783 hectares	648.0	0.0	648.0
Provisional irrigation works for 8,000 ha in modules 10, 11 and 12	319.0	0.0	319.0
Rebuilding dirt roads of Reforma canal	32.9	0.0	32.9
Rebuilding drains in the southern side of the irrigation district	75.4	0.0	75.4
Total	**1,162.3**	**12.5**	**1,174.8**

Direct Support to Farmers. Crop insurance policies did not consider earthquakes, so damage caused by this natural disaster required the creation and beginning of three Strategic Projects and one Temporary Program to help farmers meet their economic commitments with banks and to reestablish the productive capacity of their land.

The three projects and the program had an investment of 370.5 million pesos during the year 2010 (federal 309.7 million pesos and state 60.8 million pesos), with 3,568 beneficiaries, and an area of 53,448 hectares. These investments breakdown as follow (SEFOA, 2010):

1. Strategic Project of Regional Impact, to recover the productive capacity of agricultural land in the Mexicali Valley, B.C. (PRECAPS).
    a. Covered actions:
        i. Soil diagnostics
        ii. Disking
        iii. Subsoiling
        iv. Land leveling
        v. Soil amendment acquisitions
    b. Farmers benefited: 2,617
    c. Total impacted area: 36,000 hectares
    d. Investment (million pesos)
        i. Federal, 9.8
        ii. State, 6.8
        iii. Total, 15.6

2. Strategic Project of Regional Impact, to help wheat, cotton and alfalfa farmers in the Mexicali Valley and San Luis Río Colorado Valley, with 100% yield damages.
    a. Considered concepts: wheat, alfalfa and cotton crops with total yield damages
    b. Farmers benefited: 241
    c. Total impacted area: 5,890 hectares
    d. Investment (million pesos)
        i. Federal, 80.0
        ii. State, 0.0
        iii. Total, 80.0

3. Strategic Project of regional impact, to help wheat farmers with partial yield damages in the Mexicali Valley and San Luis Río Colorado Valley.
    a. Target: Wheat crops with partial yield damages
    b. Farmers benefited: 203
    c. Total impacted area: 2,000 hectares
    d. Investment (million pesos)
        i. Federal, 65.0
        ii. State, 0.0
        iii. Total, 65.0

4. Program for the temporary transfer of water rights (CONAGUA).
    a. Target: 7,000 pesos per hectare (US$1,480/acre) for agricultural fields that did not have irrigation water for the agricultural period autumn-winter 2010-2011
    b. Farmers benefited: 507
    c. Total attended area: 9,558 hectares
    d. Investment (million pesos)
        i. Federal, 66.9
        ii. State, 0.0
        iii. Total, 66.9

In 2010, an area of 36,000 hectares was impacted by PRECAPS. An additional investment is required for an area of 21,035 hectares to completely cover the total affected area.

CONCLUSIONS

1. The first action taken by the government was to reestablish water flow for urban usage and to assess the irrigation district hydraulic system, and to consider the topography of every main and secondary canal, as well as drains, monitoring the piezometric system to determine the aquifer depth, and soil sampling to determine salinity.

2. Agricultural land affected amounted to 57,035 hectares of established crops. Wheat was highlighted with an area of 43,609 hectares, then alfalfa with 11,146 hectares, cotton with 1,945 hectares and vegetables with 335 hectares.
3. The hydraulic system suffered the following damages: 57 km to the main irrigation canals (Reforma, Nuevo Delta and Revolución), 350 km of secondary canals and 380 km of drainage system.
4. The crop insurance policies did not consider earthquakes, which resulted in the creation of three Strategic Projects and one Temporary Program to help farmers settle economic commitments with banks, and reestablish the productive capacity of their land.
5. Main and secondary canal rebuilding was covered by the Irrigation District's insurance policy. Nevertheless, additional work was needed, which required an investment of 1,174.8 million pesos (US$100.6 million).
6. The three projects and one temporary program with an investment of 370.5 million pesos (US$31.7 million) were offered to the farmers to recover crop losses and to re-level their fields.

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IRRIGATION ENGINEERING IN SEISMIC ZONES — MEXICALI VALLEY, MEXICO

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ABSTRACT

On April 4, 2010 an earthquake of Richter magnitude 7.2 occurred with an epicenter south of Mexicali within the irrigated zone of Mexicali Valley. Extensive damage occurred to main and lateral canal structures, plus to field irrigation systems and the main drainage network. This paper describes the engineering for a new major irrigation water conveyance system to service the most heavily impacted zone of 80,000 acres. Considerations included identification of the causes of the damage, selection of canal versus pipeline, relocation costs of people along new routes, and improved flexibility of water delivery. Major investigations regarding soils, topography, etc. were conducted in a compressed timeline of only 4 months. Construction is anticipated to begin in December 2011.

INTRODUCTION

The Mexicali Valley in Baja California (and some area in the state of Sonora) has approximately 500,000 acres of irrigable land. The water is owned by the national government and adminstrated by CONAGUA, the Mexican equivalent of the USBR. An area CONAGUA office is responsible for the network of major canals (District 014) that distribute water to both agricultural districts and municipalities (primarily Tijuana and Mexicali cities). The major canals are maintained and operated by the "Colorado River Irrigation District, S. de R.L. I.P. de C.V.", which is an umbrella water-user organization such as the Friant Water Users Association. The Mexicali Valley is administratively and hydraulically divided into 22 "modulos" or smaller irrigation districts (water user associations), each responsible for operation and maintenance of smaller canals and direct deliveries to field turnouts (Figure 1). The "modulos" provide the board members for the S. de R.L.

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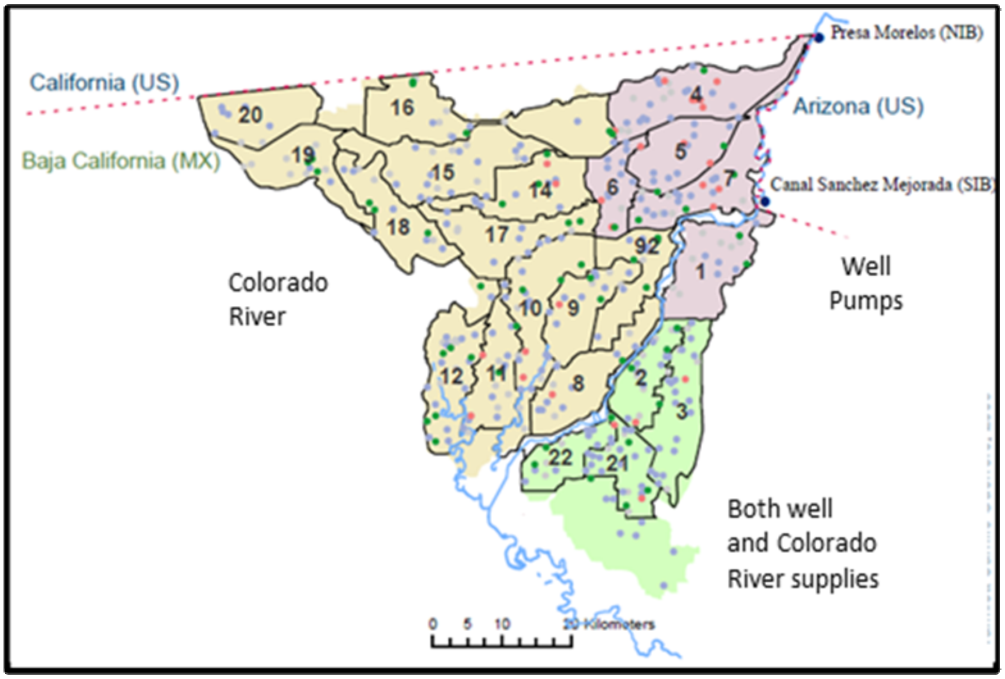

Figure 1. District 014 (Mexicali Valley) showing Modulos (by number) and sources of water (by color).

On April 4, 2010 an earthquake of Richter magnitude 7.2 occurred with an epicenter south of Mexicali within the irrigated zone of Mexicali Valley. The modulos that suffered the most damage from the earthquake were Modulos 10, 11, and 12, with about 80,000 irrigated acres. The irrigation water to those modulos was supplied by the concrete-lined Nuevo Delta Canal (about 15 miles long), which is in turn supplied by the Reforma Canal, which receives its water from the Colorado River at Morelos Dam (Presa Morelos on Figure 1). This paper focuses on the plans to rebuild/replace the Nuevo Delta Canal, which was heavily damaged.

The areas of the Valley that experienced the most earthquake damage had also recently experienced serious subsidence problems, which are attributed by some to the adjacent geothermal energy fields that may have insufficient groundwater recharge. Figure 2 shows anticipated subsidence over the next 30 years, although in some areas the 2010 earthquake caused more than twice the 30-year predicted subsidence.

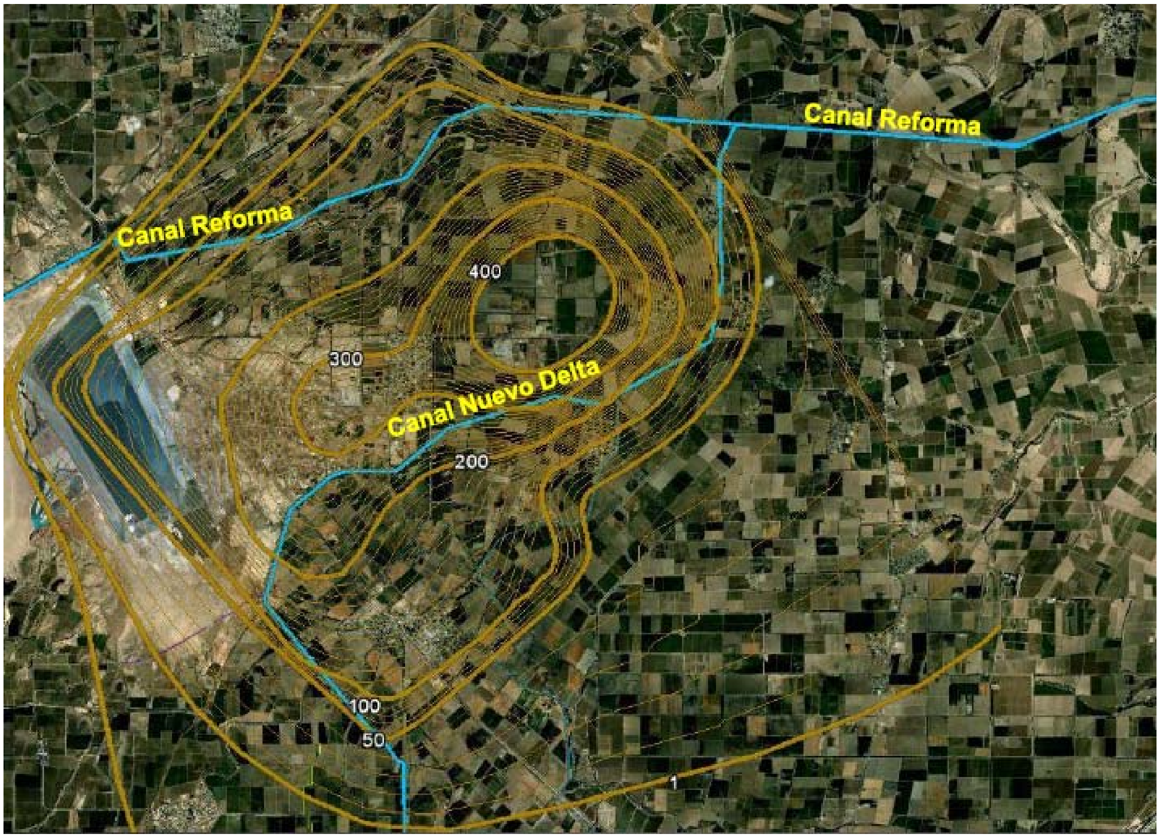

Figure 2. Lines of equal subsidence predicted by CICESE to occur within 30 years. Units are cm. The geothermal production zone is on the center left-hand side of the figure. The blue lines show the Reforma Canal (top, flowing right to left), and the old, damaged Nuevo Delta Canal (center, flowing from top to down).

Besides subsidence, the design also had to consider locations of fault lines and zones of liquifaction. Figures 3 and 4 indicate the locations of these potential problem zones.

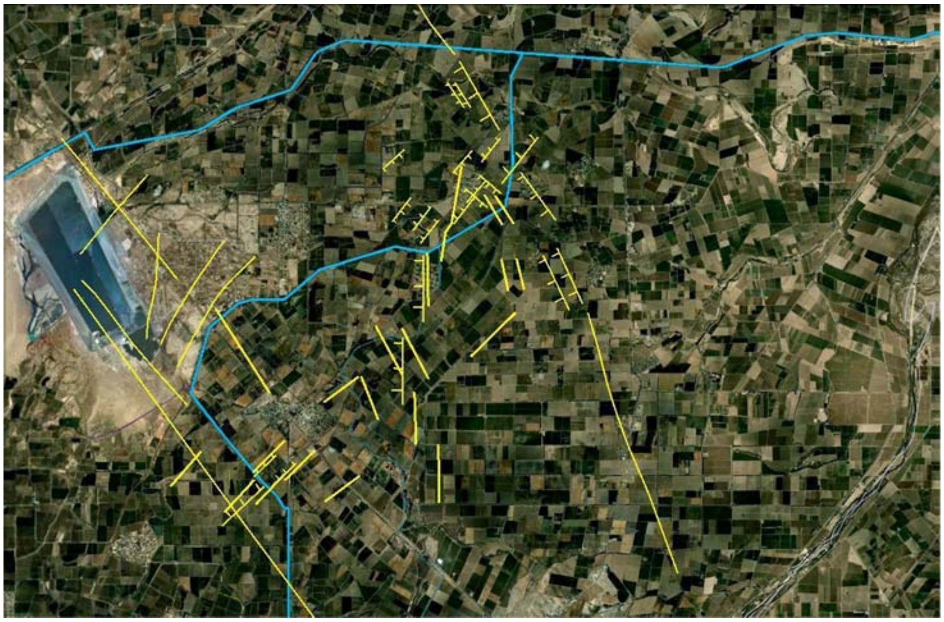

Figure 3. Fault lines in relation to the Reforma Canal and Nuevo Delta Canal.

Figure 4. Zones of liquefaction in relation to the Reforma Canal and Nuevo Delta Canal.

The agricultural fields suffered substantial damage due to a combination of subsidence and liquefaction in the subsurface. Small “volcanoes” appeared in fields across a huge area — where water flowed up from the saturated subsurface and discharged large amounts of sand plus salty water across the soil surface. Figure 5 illustrates this phenomenon.

Figure 5. Sand volcanos that arose from subsurface liquefaction.

The canals and drains suffered considerable damage. Drain embankments sloughed in, as did canal embankments.

Figure 6. Remnants of a large drain channel that completely filled in during the earthquake.

The canal damage caused by factors other than overall subsidence varied depending upon the location. The figures below give examples.

Figure 7. Slumping of embankment into the canal. Photo courtesy of CONAGUA.

Figure 8. Movement of the entire canal embankment away from the canal. Photo courtesy of CONAGUA.

Figure 9. Fissures in the embankment road. Photo courtesy of CONAGUA.

Selecting a New Route

The damaged Nuevo Delta Canal traversed multiple fault lines and liquefaction zones. Plus, it fell within zones of anticipated subsidence.

Over thirty different replacement routes were analyzed and compared in terms of economics, right-of-way acquisitions, residential relocation costs, road crossings, topography, costs, available pressure, command area, and ability to enhance existing water delivery service. These considerations were overlaid on the maps of subsidence, liquefaction, and faults. The final route is shown in Figure 10.

Figure 10. Proposed route of new canal, showing faults, subsidence, and liquefaction zones.

Designing to Minimize Future Damage

One design/construction option was to use pipelines instead of canals. Multiple large diameter (96”), steel ribbed reinforced HDPE pipes were considered as the best pipeline option, but the price was more than double that of a new canal. Furthermore, there were concerns about the ability to quickly repair such pipes, and to maintain them free of sediment.

Therefore, the focus was on how to properly construct the new canals to minimize the type of embankment failures that occurred during the April 4, 2010 failure.

If one looks at the failures that occurred in the Mexicali canal embankments during the April 4, 2010 earthquake, common circumstances in failure zones appear to be:

1. The canal banks were constructed of native materials, with a high silt percentage, that were not well compacted.
2. There was high seepage loss from the canals prior to the earthquake – indicating that the canal embankments under the cracked concrete lining, at least in many areas, were saturated.
3. A high water table existed, indicating that the soil immediately under the base of the canal and its embankment were saturated.

With the exception of localized shear caused by dispacement of soil along/crossing a fault line, the damage exhibited classic symptoms of slope instability. This type of embankment failure is sometimes associated with a different manifestation of liquifaction than was mentioned earlier (sand volcanoes in fields due to subsurface liquifaction). For canal band failure, the embankment becomes more “slippery” due to the rapid buildup of high pore pressures during cyclic shear of saturated soils. If the pore pressure builds up on uncompacted soil, the potential for slippage (shear failure) increases as compared to on compacted soils.

The new canal will incorporate the following features to minimize problems that existed on the old canal:

1. The soil will be over-excavated, filled with compated soil, and then the cross section for the new canal will be cut from the compacted soil.
2. The canal embankments and the “footing” of the canal itself will be kept dry by preventing moisture from entering from above and below. The two solutions will be:
    a. The canal will be lined with a geomembrane to prevent seepage from “above”. That geomembrane is equipped with a fuzzy material on its surface so that concrete will adhere to it. Concrete will be applied with a 3” thickness over the geomembrane. The concrete will provide mechanical protection from cleaning operations and other physical damage that might occur.
    b. A tile drain will be installed approximately 6’ below the bottom of the canal, and to the side, to help lower the water table immediately under the canal.

This will help minimize moisture from entering the embankment from below, and will possibly provide a more stable footing for the whole structure.

Operation Enhancement Features

The old Nuevo Delta Canal had almost no ability to provide flexible service to the water user associations (modulos). The old cross regulators (check structures) were manual sluice gates, and the flow measurement devices at all bifurcations and turnouts were uncalibrated.

The replacement canal, called the “4 de Abril” canal, will incorporate the following key control features:

1. A Replogle flume (broad-crested weir) at the head.
2. Long-crested weirs for check structures.
3. New standardized submerged orifice flow meters for turnouts.
4. Two regulating reservoirs, with pumps in and out to automatically maintain the adjacent canal pool water level.
5. Improved flow control and measurement at the heads of major bifurcations.

Because of the significant vandalism problems and historical challenges with SCADA and automation in the Mexicali Valley, there will be no automation except for on the pumps that put water into and out of the reservoir. The PLC controller has been specially designed by ITRC to use two simple water level probes (rather than pressure transducers) and fixed speed pumps (as opposed to using VFDs).

CONCLUSION

The 4 de Abril replacement canal for the Nuevo Delta Canal in Mexicali Valley avoids major areas of subsidence, faults, and liquefaction. The canal will be constructed with lining, drainage, and compaction to minimize embankment failure. The new canal has features that will enhance the water delivery service to the water users by providing more flexible, equitable, and dependable deliveries. Construction is scheduled to begin in December of 2011.

NEAR FAILURE OF THE ALL AMERICAN CANAL IN SOUTHERN CALIFORNIA DUE TO A 7.2 MAGNITUDE EARTHQUAKE IN APRIL 2010

Bob Dewey[1]

ABSTRACT

On Easter Sunday, 2010, a 7.2 magnitude earthquake struck northern Mexico near Mexicali. One key structure, the All-American Canal, which diverts Colorado River water from the Imperial Reservoir and delivers irrigation water throughout the Imperial Valley, was heavily damaged. The canal parallels the California/Mexico border and a siphon carries water across the New River in southern California only 22 miles from the earthquake epicenter. The earthquake damaged the concrete canal lining, separated vertical and horizontal joints at the inlet of the siphon and wasteway, liquefied materials in the New River channel, and opened up wide cracks and fissures in the 40-foot-high embankment fill and riverbank supporting the canal, gate structure, siphon and wasteway. Concentrated seepage was observed exiting near the toe of the embankment fill between the siphon and the wasteway. Many aftershocks occurred, but the seepage remained steady for ten days after the April 4th main shock. On the 11th day, the quantity of seepage suddenly increased approximately ten fold. That evening a significant aftershock of 4.8 magnitude occurred and the seepage increased even more, causing internal erosion of embankment materials to begin in earnest. This paper discusses the incident, what mitigation actions were taken that night to save the siphon structure, follow-up investigations and engineering studies and construction of the repairs.

BACKGROUND

The All American Canal (AAC) is an open channel that conveys water of the Colorado River into the Imperial Valley in California and is the valley's only water source. The AAC provides water for domestic use for nine cities and irrigates over 450,000 acres. It is the largest irrigation canal in the world, with a design capacity of 15,155 cfs at its origin. The main canal is 82 miles long with a total drop of 175 feet, a width of 150 to 700 feet, and a depth of 7 to 50 feet.

This paper focuses on the canal siphon over the New River. The siphon receives water from the open channel of the AAC and conveys it through two 15.5-foot diameter elevated steel pipes across the New River canyon and discharges the water into another open channel. Construction was completed in 1938. The facility is located approximately 1 mile west of Calexico and is operated and maintained by the Imperial Irrigation District. Approximately one third of the valley's agricultural acres are irrigated by water carried through the siphon. The elevation of the top surface of the canal water as it approaches the siphon is approximately 45 feet above the New River. The top of the AAC embankment in this area is typically 15 feet above the original ground elevation at

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the river banks (above the canyon). This portion of the concrete-lined canal is trapezoidal in cross-section with the following typical dimensions: 22-foot bottom width, 65-foot top width; typical water depth is 11 feet. Flow carried by the canal at this location typically varies from a peak of 1800 cfs to a minimum of 600 cfs during winter months; the peak flow capacity is 2700 cfs.

The siphon has three main sections: the inlet structure, the siphon pipes and the outlet structure. Each section contains various components that are described below. The pipes suffered minor damage and the outlet performed as well or better than the inlet, so what is presented in this paper mostly pertains to the inlet structure. The inlet structure at the north end of the siphon has three operational components and one support structural component. The north end of the siphon and its pertinent components is shown in Figure 1.

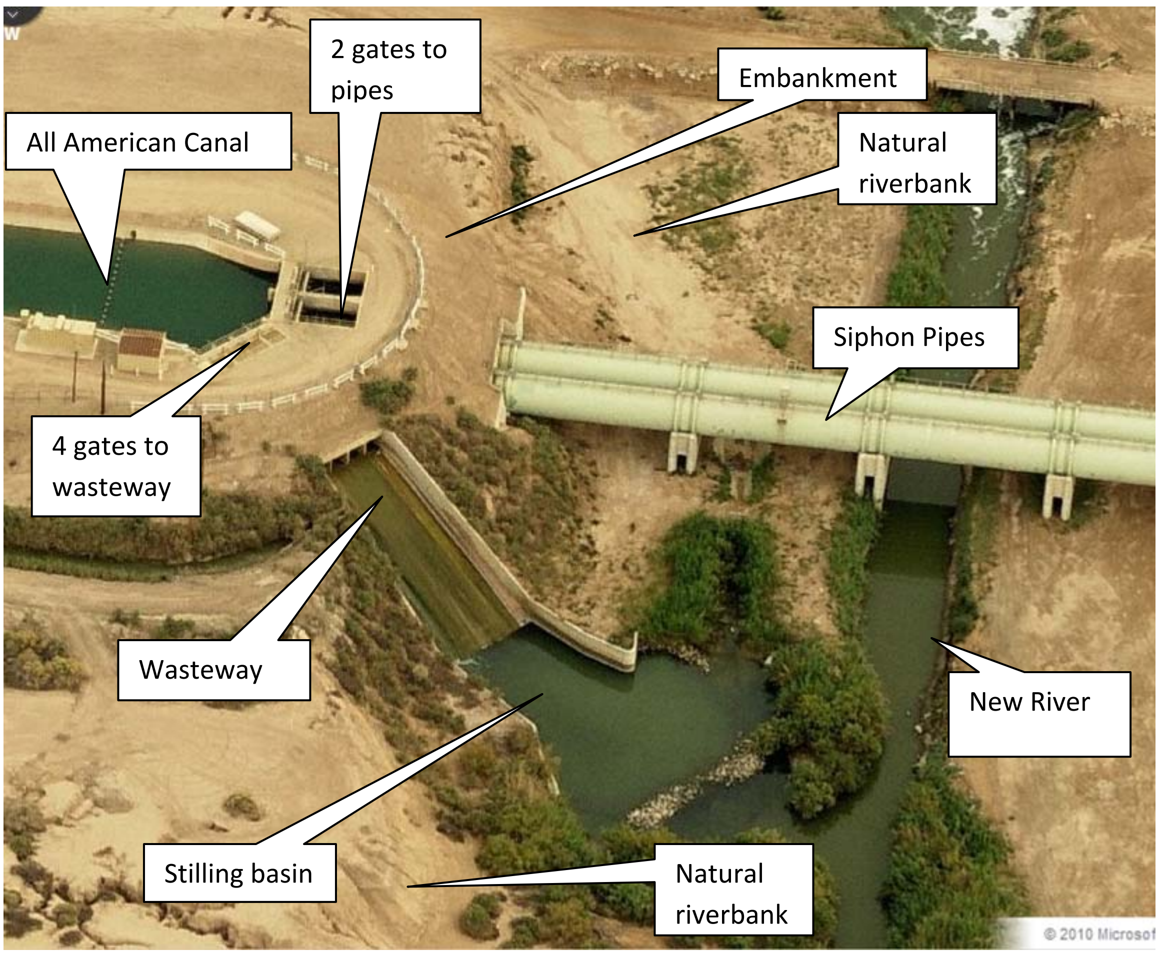


Figure 1. View of the North End of the All American Canal siphon inlet at the New River crossing

Canal water flow enters two 16 ft wide by 18 ft high by 34 ft long box culverts, each housing a radial steel gate structure. The invert then drops 18 feet in elevation as the culvert cross-sections transition from rectangular to circular as water enters the siphon pipes. The structure is supported by concrete piles, typically 40-feet long on an 18.5-foot grid spacing, extending into the underlying terrace deposits. The outer toe of the culvert transition section is also supported by sheet piling.

Canal water can also flow to a wasteway used to spill excess canal water to the New River. This component is a concrete box culvert containing four 8-foot by 6-foot cells, 69 feet in length, each housing a radial gate. The structure is also supported by concrete piles, typically 40-feet long on an 8.5-foot grid spacing, extending into the underlying terrace deposits. A vertical concrete pier nose was constructed between the Wasteway Gate & Box Culvert and the Canal Gate & Culvert Sections, directing flow to each; the pier nose radius is 9 inches wide by 23 inches long, and 18 feet in height, 13 feet of which is submerged.

The Wasteway Chute & Box Culvert discharges water onto a 12-inch thick, 80-foot long concrete chute that drops over 40 feet in elevation to an energy dissipation stilling basin. A 0.75-inch wide expansion joint separates the culverts and the chute. The width of the chute varies from 33.5 ft at the top to 50 ft at the bottom. The chute is contained on each side by a 12-inch thick, 9-foot high, concrete wall for the initial 57.5 feet; at that point the top of wall runs horizontally, increasing in height to 19 feet at the chute termination, and continuing at that height along each side of the stilling basin. The stilling basin is 50 feet wide and 37 feet long with an invert elevation of -57.50 feet msl (note: the Imperial Valley is below sea level). The Wasteway chute and stilling basin are supported by compacted structural fill. Sheet piling is installed at the perimeter of the stilling basin to cut off seepage. A 48-foot long, 3-foot thick layer of large riprap is installed at the stilling basin discharge point.

A concrete flume that discharges flow from an unlined drainage ditch on the west side of the canal to the Wasteway Chute enters through the southern wall of the Wasteway Chute 21.5 feet downstream of the top of the chute. The flume is 34.5 feet long, varying in width from 6 to 4 feet at the chute wall.

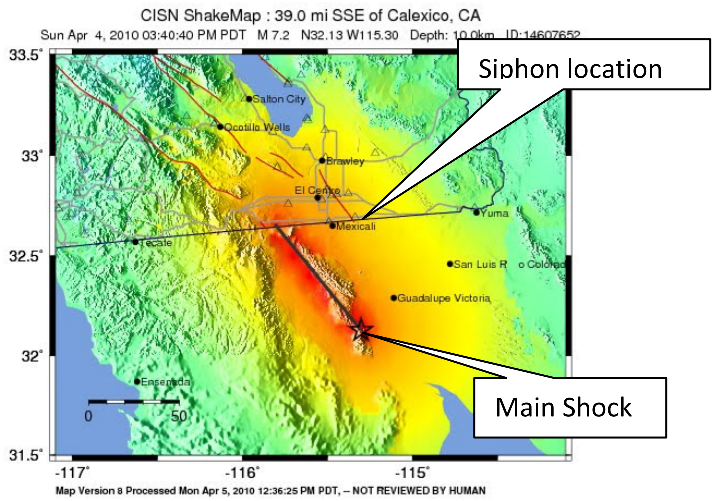
Supporting the canal and all of the above operational components is a trapezoidal earthen embankment (upper embankment). On average, it is 100 feet wide at the base with a top width of 24 feet and a height of 17 feet. Outside slopes range from 1.5(H):1(V) to 2(H):1(V) and inside slopes are 1.67(H):1(V). The canal embankment was constructed in 1938 of soil from the surrounding area, placed and compacted on existing ground adjacent to the near vertical banks of the New River. The soil particles range from sand- to clay-sized, predominately a low plasticity silt that is highly erodible. The embankment is generally dry; however, a more sandy layer at the bottom of the embankment is saturated. Some of the alluvial materials in the river channel that are saturated liquefied during the earthquake. The top elevation of the canal embankment is 50 feet higher than the New River.

The canyon wall underlying the toe of the upper embankment is supported and strengthened by two earth-filled concrete crib retaining walls located on either side of the siphon pipes. The walls are approximately 23 feet high and 25 feet wide; the outward toe of each wall is supported by sheet piling extending to a depth of 20 feet. Compacted backfill (lower embankment fill) has been placed against the front of each cribwall, covering a portion of the face. The cribwalls and lower embankment fills also provide support and confinement for the Inlet Structure. Lower embankment fills are located over the alluvial soils of the floor of the canyon. These crib retaining walls and lower embankment areas are critical to the stability of the upper embankment adjacent to the canyon. Weakening or failure of these structures could result in the differential settlement and/or failure of Inlet Structure components and/or the canal.

Besides concerns at the structure with its earthquake performance, there are health and security concerns. The New River water is contaminated with E. coli, and human contact must be avoided. Additionally, because the structure is less than 1 mile from the border with Mexico, security is tight during the day at the siphon. Continuous monitoring through the night was not allowed since security was not present.

THE EARTHQUAKE

The Sierra El Mayor earthquake of Sunday April 4, 2010, occurred in northern Baja California, near the Mexico-USA border at shallow depth along the principal plate boundary between the North American and Pacific plates (see figure 2). This is an area with a high level of historical seismicity, and also it has recently been seismically active, though this is the largest event to strike in this area since 1892. The April 4th earthquake appears to have been larger than the M 6.9 earthquake in 1940 or any of the early 20th century events (e.g., 1915 and 1934) in this region of northern Baja California. The earthquake ruptured the surface for a distance of 100 kilometers from the Gulf of California to the California-Mexico border, with displacements ranging as high as 2-3 meters. Offsets were confirmed along 28 kilometers of the Borrego fault, north to the international border. Fault motion was oblique, down to the east with a component of right-lateral motion.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 2. Distribution of intensities from the Sierra El Mayor earthquake of Sunday April 4, 2010. (http://earthquake.usgs.gov/earthquakes/eqinthenews/ 2010/ ci14607652/#maps).

Earthquakes having magnitudes as high as 7 have been historically recorded from the section of the Pacific/North American plate boundary on which the April 4, 2010 earthquake occurred. The 1892 earthquake occurred along the Laguna Salada fault system, but surface offsets associated with the 1892 event lie farther northwest than the April 4th main shock's epicenter. The 2010 event's aftershock zone extends to the northwest, overlapping with the portion of the fault system that is thought to have ruptured in 1892. A 1940 Imperial Valley earthquake approached magnitude 7, though it occurred farther to the north and on the Imperial fault. An event of M 7.0 or 7.1 occurred in this region in 1915 and a M 7.0 to 7.2 in 1934 broke the Cerro Prieto fault with up to several meters of surface slip.

Over 700 aftershocks were recorded in the first two days after the main shock of the earthquake (see figure 3). By April 14, ten days after the main shock, more than 4000 aftershocks were recorded and at least 80 were greater than magnitude 4 (see figure 4). A month after the main shock, 150 to 200 seismic events were still being recorded daily.

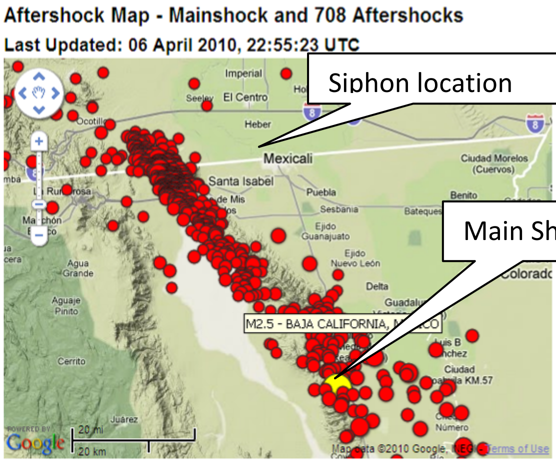


Figure 3. Aftershock map two days after the Sierra El Mayor earthquake of Sunday April 4, 2010.

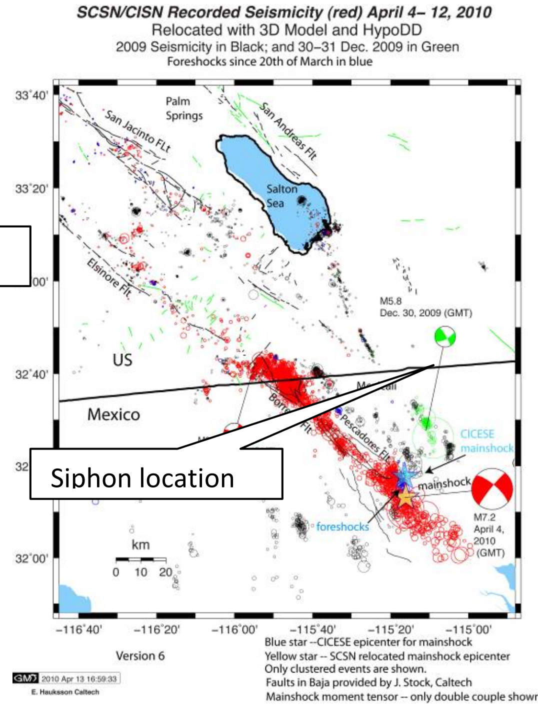


Figure 4. Aftershock map 8 days after the El Mayor earthquake.

DAMAGES

Fatalities occurred in Mexicali, Mexico where the severest of the infrastructure damage occurred. Damage to buildings, roads, bridges and water resources was widespread in the United States across California and Arizona. The Imperial Irrigation District suffered structural damages throughout its entire water distribution system in the Imperial Valley of southern California.

The siphon structures that carry water over the New River survived the event, but just barely. Water sloshed out of the canal during the event. Embankment fills and concrete structural components were damaged from ground deformation resulting from liquefaction, lateral spreading, and ground lurching associated with the earthquake. This brief description covers some of the damage in the siphon inlet area. Similar damages occurred at the outlet. Fortunately, the siphon pipes suffered no damage despite their supports shifting laterally up to 6 inches in the liquefied riverbed materials (Figures 5 and 6). There was severe cracking and deformation of both the embankments and natural river banks supporting the canal and siphon structures (crack map, Figure 7 and Figure 8). Cracking was evident on several concrete components of the inlet and the wasteway. All of the noses of the piers where canal water enters the siphon pipe and wasteway gate structures suffered vertical cracks from top to bottom (figure 9). Concrete joints separated in the canal lining (Figure 10). The joint between the wasteway gate box culvert and the chute opened as the chute slid downward relative to the culvert at the top of the slope (Figure 11). The vertical walls of the box culvert and wasteway chute cracked (Figure 12). Seepage of canal water began exiting from beneath the wasteway chute and the embankment supporting the inlet structure (Figure 13).

The seepage mentioned above was clear and steady for ten days after the earthquake. The Irrigation District kept a watchful eye on the seepage as many aftershocks were occurring, some of significant magnitude. On April 13th, the seepage increased to 10 gpm and began to carry sediment. The District called the Bureau of Reclamation for advice and engineers were sent to the site the next day. By the time they arrived, the seepage had increased to about 20 gpm. They advised to start to arrange for placement of a filter blanket the following day. The engineers visited material suppliers in the area the afternoon of April 14th to locate appropriate materials and construction equipment. During the evening, a magnitude 4.8 aftershock occurred and the seepage increased to about 30 gpm and the sediment had increased 10 to 15 times. A seepage and piping failure of the embankment supporting the canal and the wasteway was progressing rapidly. Reclamation advised the District to start the filter blanket placement immediately. While waiting for the materials and equipment to arrive, the engineers built up a pool at the exit with sandbags to backpressure the flow and buy a couple more hours (Figure 14). This system began to fail just as the filter and drain materials, lights and earth moving equipment arrived on site. They excavated gingerly into the embankment and placed the filter blanket over the seepage exit points through the night (Figure 15). The first placements just washed away. If materials didn't wash away, the seepage found a new path to exit. Coarse materials were placed into the flow to avoid washing away and redirecting the flow. An engineered filter was constructed adjacent to the flow. Finally, a closure section of filter materials was placed over the placement of coarse materials which captured and filtered all of the flow (Figure 16). By the morning, seepage had reduced and become clear discharging through the filter blanket (Figure 17).

Figure 5. Siphon pipe support column

Figure 6. Soil displaced around siphon pipe support

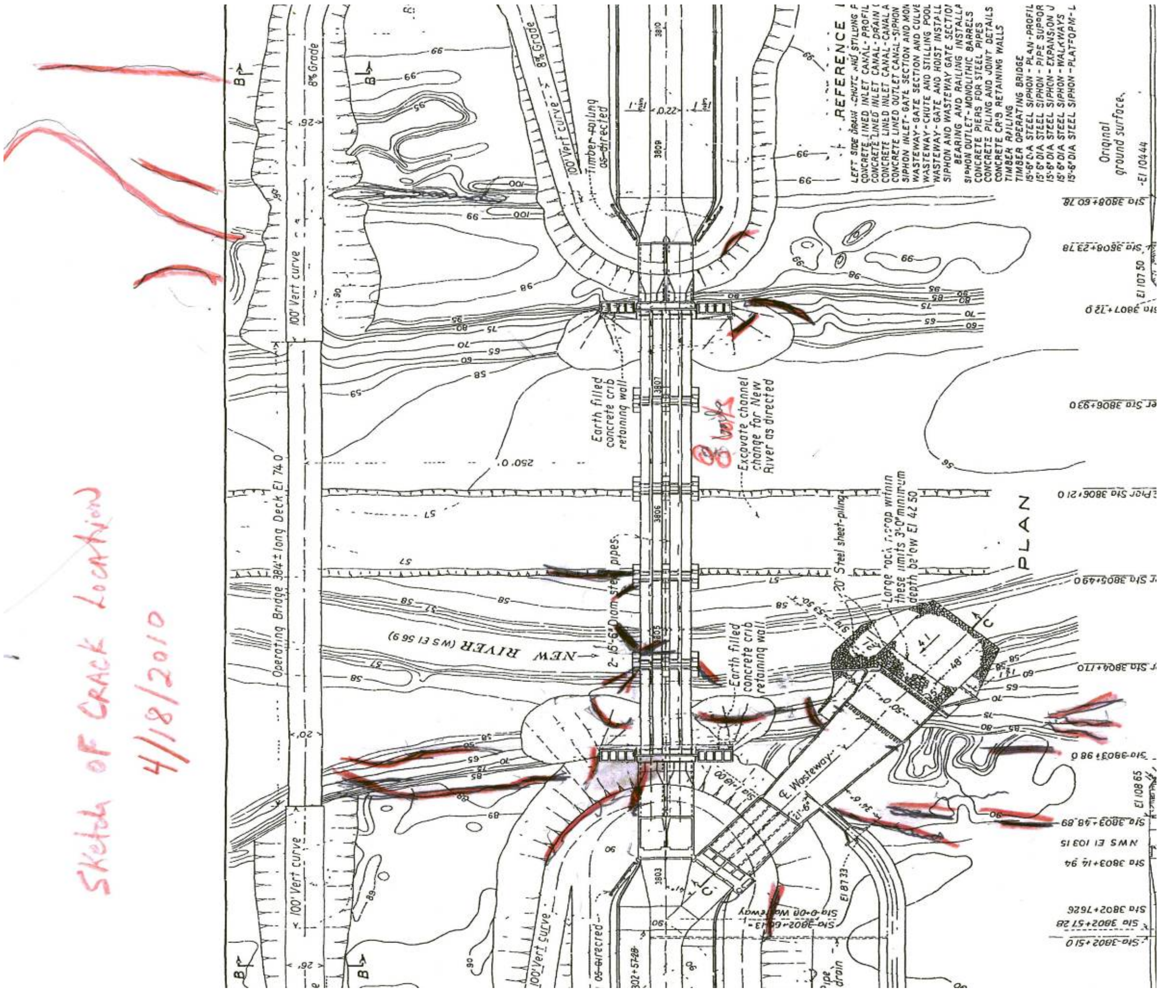


Figure 7. Plan drawing of the siphon structures and cracks mapped two weeks after earthquake.

Figure 8. Cracks in the riverbank adjacent to the siphon.

Figure 9. Bull nose crack in pier at entry to the siphon

Figure 10. Separated joint in the canal lining upstream of the siphon

Figure 11. Vertical offset of the joint at the top of the chute

Figure 12. Cracks in the wall of the wasteway

Figure 13. Seepage exiting the embankment fill adjacent to the wasteway wall

Figure 14. Sandbags used to backpressure the seepage exit.

Figure 15. Excavation into the seepage exit with gravel materials on hand.

Figure 16. Filter and gravel blanket materials during placement

Figure 17. Completed filter and drain blanket with seepage safely being collected and discharging clear water.

FOLLOW UP

Immediately following the near-failure incident, continuous daytime monitoring was established. Monitoring could not be performed through the night because there was no security and it was too dangerous to be approximately ½ mile from the international border without protection. Reclamation provided geotechnical engineers for the first month and prepared a visual inspection checklist for the Imperial Irrigation District to follow to make the monitoring efficient. The District set up a command center on site with many modes of communication available. Surveyors monitored the site closely for additional movements. Existing piezometers and inclinometers were read multiple times per day. Daily conference calls continued for many months after the incident.

A failure mode analysis was performed in order to establish focus on additional investigations and potential long term repairs. This was a collaborative effort with engineers and geologists from Reclamation and the Irrigation District. Failure modes for the siphon and the wasteway were considered separately. All failure modes were assumed to be initiated by an earthquake. The failure mode event trees developed are as follows:

Wasteway (seepage failure):

→ Earthquake occurs - leads to liquefaction of foundation/fill
→ Seepage paths connect, voids connect/line up
→ Water enters from various sources including: canal (bullnose crack/open joints), saturated zones in embankment, embankment foundation, open joint at top of wasteway joint, pressurized water in foundation, and drainage ditch
→ Erosion initiates from toe
→ Roof forms
→ Channels/cracks/voids enlarge and connect to source
→ Canal lining falls into large erosion feature
→ Canal water is lost into breach

Wasteway (stability failure)

- → Earthquake occurs - leads to liquefaction of foundation/fill
- → Shear strength is reduced in foundation materials and fill materials
- → Lateral spreading of fill
- → Wasteway chute moves downstream
- → Stilling basin moves downstream
- → Fill beneath gate structure settles or moves with shear failure
- → Canal lining falls into settled soil
- → Lining fractures/joints open
- → Canal water is lost through fractured lining

Siphon

- → Earthquake occurs
- → Differential settlement, structures move out of phase with each other, and/or slope instability occurs
- → Structure pulls apart at: canal/gate location, pipe joints, pipe/siphon location
- → Hydraulic connection to weak canal lining
- → Canal lining settles into settlement of supporting fill
- → Lining fractures
- → Canal water is lost through broken lining

Additional investigations were performed to further define the failure modes. Subsurface investigations included a 30-inch vertical drill hole through the embankment fill into the foundation, additional smaller drill holes from the top of the embankment and test pits at the toe of the embankment into the natural riverbank materials. Laboratory testing was performed on soil samples collected for material physical properties and shear strength. Most of the soil samples contained about 90% passing the #200 sieve. Some samples showed plasticity indices of around 10. Direct shear testing results varied from about 18 to 33 degrees and up to 250 psf cohesion peak shear strength on both undisturbed and remolded samples. With this data and new topography of the site, slope stability analysis was performed. The slope stability analysis demonstrated two major findings: 1) marginal stability with the shear strength of the slope materials at a reduced residual value as a result of the movements of the structures, and 2) earthquake accelerations less than those experienced in the April 4, 2010 earthquake reduce the factor of safety to below 1.0 indicating instability of the embankment and foundation supporting the siphon inlet structures.

While the investigations were being performed, 1,200 cfs continued to flow through the canal and siphon. The weather was heating up and the demand for water was increasing. Underwater dive inspections to see the condition of the joints of the canal lining at the entrance structure were considered but not attempted due to safety. Underwater video inspections were attempted, but the water was flowing too fast and the clarity was not sufficient. The best idea tried was strapping a video camera to the end of the long arm of a backhoe. Still, while these images showed some likely open horizontal joints, the images were murky and not fully conclusive. Video cameras were also inserted into the drains beneath the canal and along the side of the wasteway stilling basin which showed them to be in great shape after the many years of service.

Dye testing was performed to try to further isolate the source of the seepage water. Dye was inserted into the flowing canal water, wet wells adjacent to the canal, a void adjacent to the canal and the opened joint at the top of the chute of the wasteway (Figure 18). Dye was observed exiting from the drains in the water of the wasteway stilling basin 15 seconds after being introduced into the opened joint at the top of the chute (Figure 19). It was concluded that interconnected voids exist beneath the entire chute, from the top to the bottom. Voids were also thought to exist beneath the box culvert immediately upstream of the chute because this structure was supported on piles and would have remained high if the soil settled beneath it. To find the voids, holes were drilled through the floor of the box culvert and ground penetrating radar (GPR) was performed on the chute and box culvert. Surprisingly, no voids were found beneath the box culvert. A concentration of anomalies was observed with the GPR (Figure 20) through the floor of the chute which was interpreted to be voids. GPR was also performed through the walls of the box culvert, but no indications of voids could be found associated with this structure.

Figure 18. Introducing dye into the open joint at the top of the wasteway chute

Figure 19. Dye coming out in the stilling basin at the base of the wasteway 15 seconds after it was introduced at the top of the wasteway.

The walls of the box culvert and chute are cracked and water flows through the cracks. The water coming through the wall of the chute as shown in Figure 12 is close to where the seepage incident occurred. Its observation was an important part of the visual inspection program. Crack meters were placed across the chute cracks and they continue to show the cracks opening as aftershocks keep occurring.

A hazard classification study was conducted by Reclamation for the areas downstream of the siphon location assuming failure. It found major economic damages from the failure of the canal or siphon structures, but loss of life is not expected.

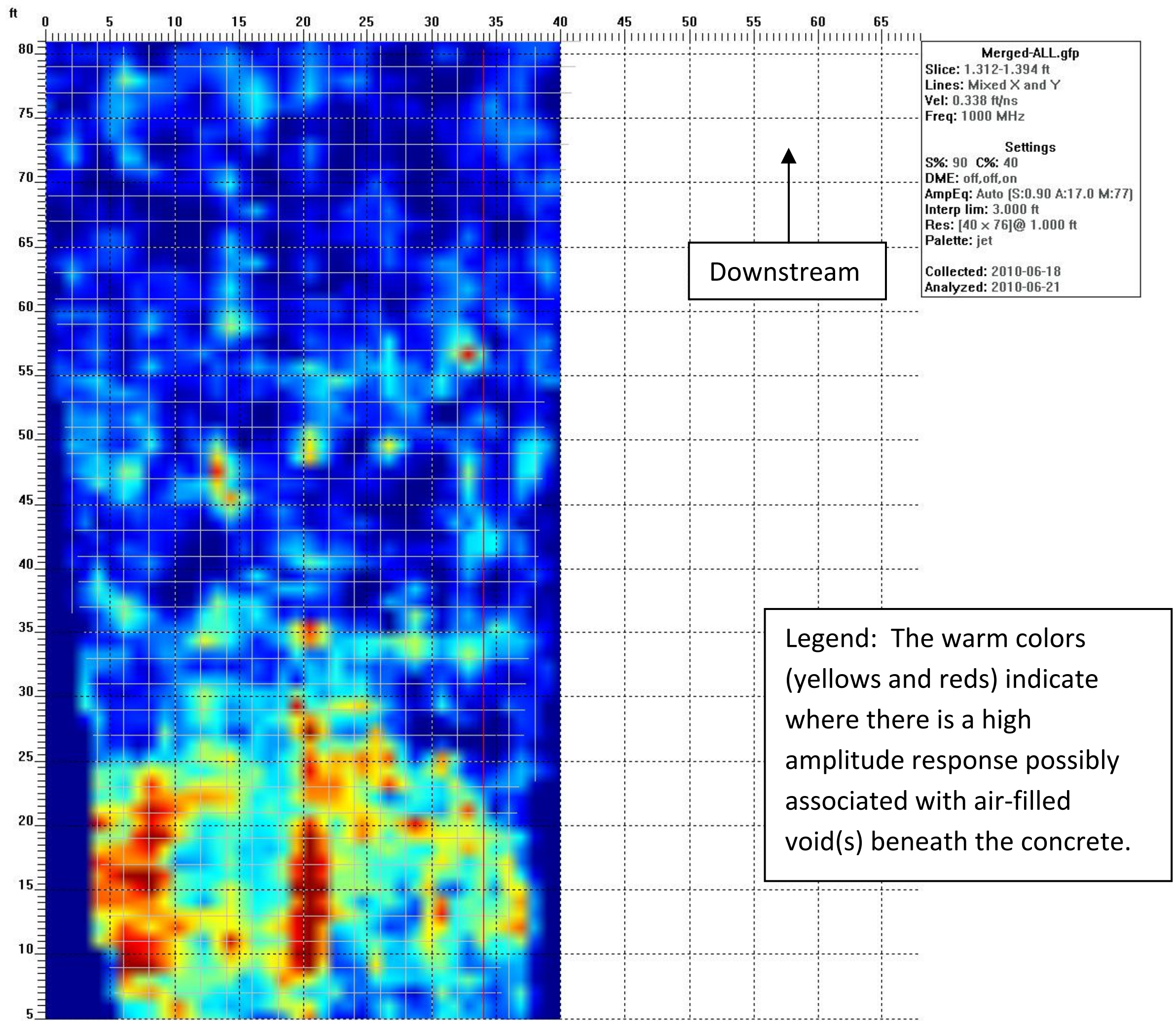


Figure 20. GPR Depth slice looking at the reflectivity near the approximate bottom of the concrete slab across the wasteway structure.

DESIGN AND CONSTRUCTION OF REPAIRS

Repairs were designed that were conceived based on the failure mode analysis mentioned above. The repairs focus on the wasteway structure; stability of the embankment that supports the canal, siphon and wasteway; and known cracks and joint separations. The repairs are intended to bring the structures to their condition that existed prior to the earthquake.

To address the instability of the embankment and underlying natural riverbank materials which support the canal, siphon and wasteway structures; a keyed berm and buttress was designed. The buttress is keyed into the river channel deposits to reach materials that are considered less liquefiable. The embankment and natural river deposits exist currently at a reduced, residual strength on critical slope shear surfaces due to movements and shearing during the earthquake. To bring the slopes back up to the level of stability they had prior to the earthquake, the outside slopes of the buttress will be flatter than originally designed and constructed (Figure 21). Internal to the berm and buttress, filter and drainage zones will be included to intercept potential seepage paths to daylight. The extent of the berm and buttress covers the abutments of the siphon on both sides of the river (Figures 22, 23 and 24).

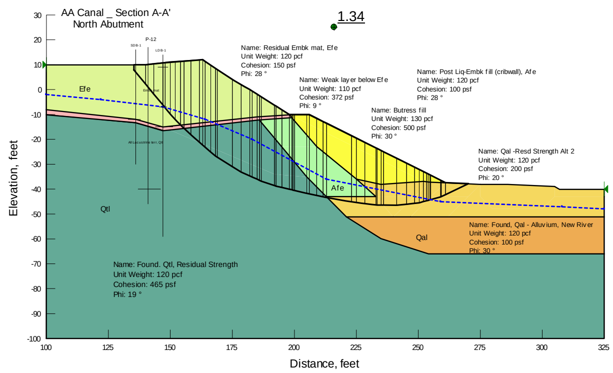


Figure 21. Stability Analysis of the Buttressed Slope

Figure 10. Placement of Materials for the Buttress at the South End of the Siphon

Figure 23. Left Side Buttress at the South End of the Siphon

Figure 24. Right Side Buttress at the South End of the Siphon

To address the voids beneath the wasteway chute, low pressure grouting was performed. Holes through the chute slab were spaced on a grid pattern and injected with cement grout (Figures 25 and 26). The pattern was influenced by the GPR survey and adjusted, as needed, for closure. Voids were found beneath the slab up to four feet deep. It took 80 cubic yards of grout to fill the voids beneath the slab.

Figure 25. Drilled Holes Prepared for Grouting on the Wasteway Chute

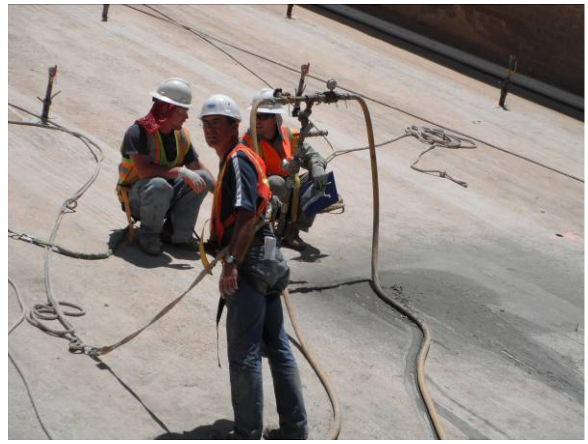


Figure 26. Low Pressure Grouting Beneath the Wasteway Chute

To address the stability of the wasteway chute, underpinning / bracing of the sloping portion of the spillway by the construction of a series of piles or piers that would be installed on the outside of the spillway walls that has been designed (Figure 27). Once the piles are installed, the spillway walls will be anchored to them. This measure of correction is not meant to raise the stilling basin back to a pre-earthquake elevation but to stabilize it at its current state which would allow ongoing operations with pre-earthquake use and functionality. The piles/piers will serve to prevent further movement and settlement of the sloping portion of the spillway structure.

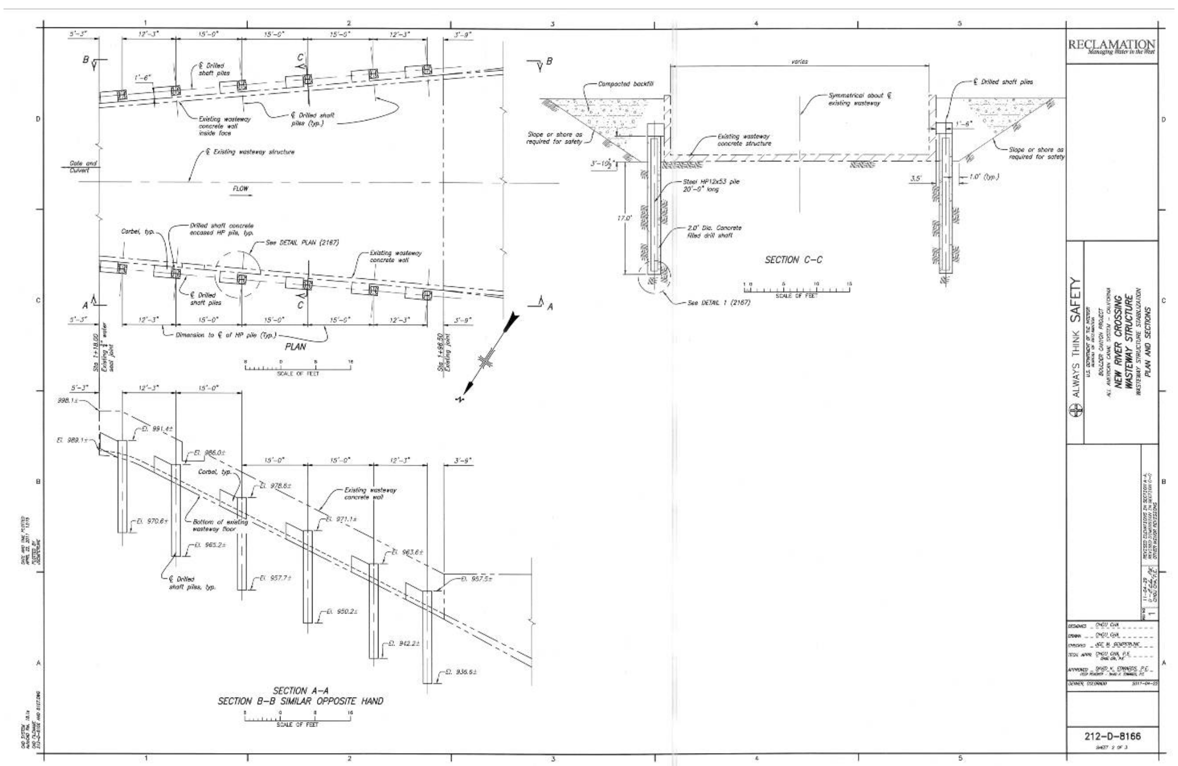


Figure 27. Design Drawing of the Wasteway Chute Support System Repair

To repair the joint separation at the top of the wasteway chute, elastomeric sealant will be used to fill the joint. To repair the cracks in the nose of the pier in the siphon inlet structure, the cracks were drilled out from the top to the bottom of the pier, cleaned and then injected with an epoxy sealant (Figures 28 and 29).

Figure 28. Drilling Vertical Holes through Cracks in the Pier

Figure 29. Epoxy Sealant being Injected into the Cracks of the Pier through the Drilled Holes

Other alternatives were considered, such as complete replacement of the wasteway and stilling basin. Consideration was given to complete replacement of the entire siphon structure and re-routing the canal to a new crossing location over the river. This was attractive since the structure is so old and should be upgraded to current seismic standards, but this would have been very costly. Continued water delivery would have to occur during construction. Other repairs are going to be needed at the existing siphon that are not discussed here, such as to the bridge crossing the New River and to the right lateral drain that discharges into the wasteway.

The Imperial Irrigation District lead the way through the emergency, exploration, design and analysis, contracting and construction. The District's field crews have been working tirelessly under difficult conditions and effectively completed critical construction to save the siphon structure. Many of the Imperial Irrigation District's personnel and managers have put in countless extra hours since the earthquake emergency and have always been extremely cooperative with Reclamation engineers and others to achieve success at every turn of the project. Support has been provided by the Federal Emergency Management Agency and the California Emergency Management Agency to bring the facility back to a condition it was before the earthquake. Construction has been phased and will be completed in 2011. All the while, the District has continued to meet its water demands by operating the canal, siphon and wasteway with great care. Visual monitoring continues on a frequent basis to assure the safety of this vital component of the country's infrastructure.

DECISION MAKING UNCERTAINTIES DURING THE TENNESSEE FLOOD OF 2010

W. Martin Roche[1]

ABSTRACT

The Tennessee flood of May 2010 caused over $2 billion in damages, and the death of 26 people. During the flood event there were some breakdowns in communications between the National Weather Service (NWS), the U. S. Army Corps of Engineers (USACE), the U. S. Geological Survey (USGS), and state and local emergency management agencies. These breakdowns resulted in numerous revisions to the forecasted flood peak, and a lack of public awareness of the urgency of the situation and of the extent of the area that would be impacted. A need to update flood forecasting models was also identified.

This paper covers the Tennessee flood of May 2010, the breakdown of communications that took place, and the measures that are being taken to improve communications among Federal agencies and between Federal, state and local emergency management agencies. It also discusses the potential for a major earthquake in Tennessee, which could cause a much more severe disaster than the flood of 2010. Lessons learned should assist irrigation and water districts in preparing for and responding to emergency situations.

INTRODUCTION

The Tennessee flood of May 2010 caused over $2 billion in damages, and the death of 26 people. During the flood event there were some breakdowns in communications between the National Weather Service (NWS), the U. S. Army Corps of Engineers (USACE), the U. S. Geological Survey (USGS), and state and local emergency management agencies. These breakdowns resulted in numerous revisions to the forecasted flood peak, and a lack of public awareness of the urgency of the situation and of the extent of the area that would be impacted.

As damaging as the Flood of 2010 was, there is potential for an earthquake in Tennessee that could cause a much more severe disaster.

THE TENNESSEE FLOOD OF 2010

Flood Timeline

On Tuesday, April 27, 2010, the National Weather Service (NWS) predicted heavy rain for western and central Tennessee for the weekend of May 1 and 2. On Thursday, April 29, the NWS issued a flood potential outlook for streams and rivers to exceed flood stages over the weekend. On Saturday, May 1 heavy rainfall began, flash flooding occurred on streams, and a flood warning was issued for the Cumberland River. On

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Sunday, May 2 torrential rain continued, and stage forecasts for the Cumberland River were continually updated by the U. S. Corps of Engineers (USCE) and the NWS. The heaviest rain in the Cumberland River drainage occurred in uncontrolled basins, resulting in record flooding. On Monday May 3 the Cumberland River peaked at 51.86 feet, almost 12 feet above the flood stage of 40.00 feet. Flood stage was exceeded for about 66 hours (Figure 1). On Tuesday, May 4 President Obama declared a Federal Disaster for 49 counties in Tennessee, providing federal aid for individuals, businesses, and public agencies impacted by the flood (Figure 2).

Rainfall Amounts

Fourteen to 15 inches of rain fell over a large area of western and central Tennessee in less than 36 hours on May 1 and 2, 2010, with some areas exceeding 20 inches of rain (Figure 3). The rainfall amount was estimated to be a once in 1000 year event some areas. 13.57 inches of rain fell at the Nashville International Airport; the previous record for the entire month of May was 11.04 inches.

Flood Impact

The Tennessee Flood of 2010 caused an estimated $2 billion in damage, with an estimated $600 million in damage to public facilities that are eligible for federal aid for repairs. Loss of economic activity has been estimated at $2.65 billion. Over 1,500 homes were destroyed and over 10,000 people were displaced. Over 11,000 properties were damaged and over 2,800 businesses were closed, many permanently.

Statewide there were 26 deaths, with 11 in the Nashville area. Most of the deaths were due to drowning in smaller tributary streams which rose rapidly on May 1 and 2, 2010. One fatality occurred from recreational use (tubing) on a normally small stream. There were over 1,000 rescues of stranded residents and motorists.

In the Nashville/Davidson County Metro Area (Figure 4) alone the cost of emergency services, provided primarily by police and fire personnel, topped $10 million (Table 1). Over 110,000 tons of debris were removed, at a cost exceeding $13 million. The estimated damage to public facilities was almost $94 million; including water, wastewater, and storm drain systems, roads, schools, and park and recreation facilities. Although there was major damage to water treatment and distribution systems, by encouraging water conservation the Metro Area did not have to issue an order to boil water for potable uses. Boil water orders were issued in 10 other areas throughout Tennessee.

Damage to major non-governmental facilities in the Nashville area included damage to the Grand Ole Opry ($20 million), Opryland Hotel ($75 million), Opry Mills Mall ($200 million), and Schermerhorn Symphony Center ($40 million). With the exception of the mall, these facilities have been repaired and reopened; due to insurance issues and a declined economy, the mall may never reopen.

In addition to the efforts of public agencies and businesses, volunteers assisted with the recovery. One organization, Hands Over Nashville, contributed almost 90,000 hours to cleanup and repair.

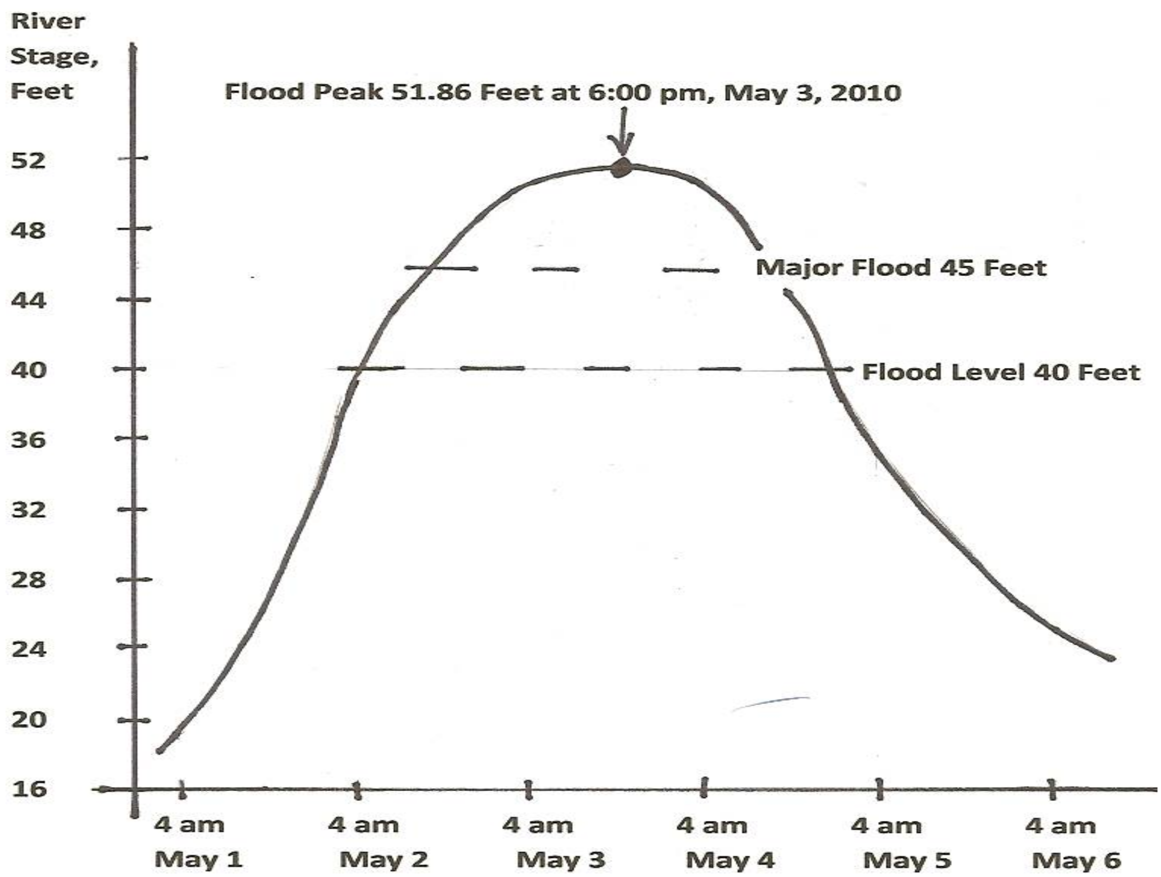

Figure 1. Cumberland River Stage at Nashville, May 1–6, 2010.

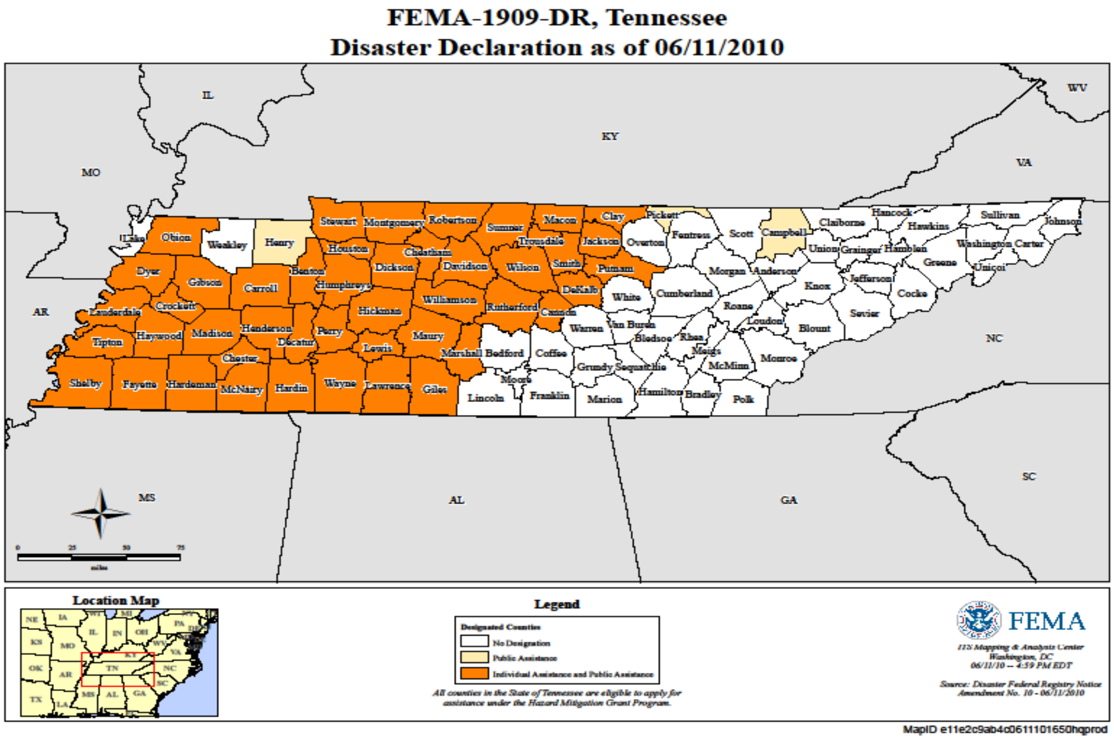

Figure 2. Tennessee Counties Declared Disaster from May 2010 Flood

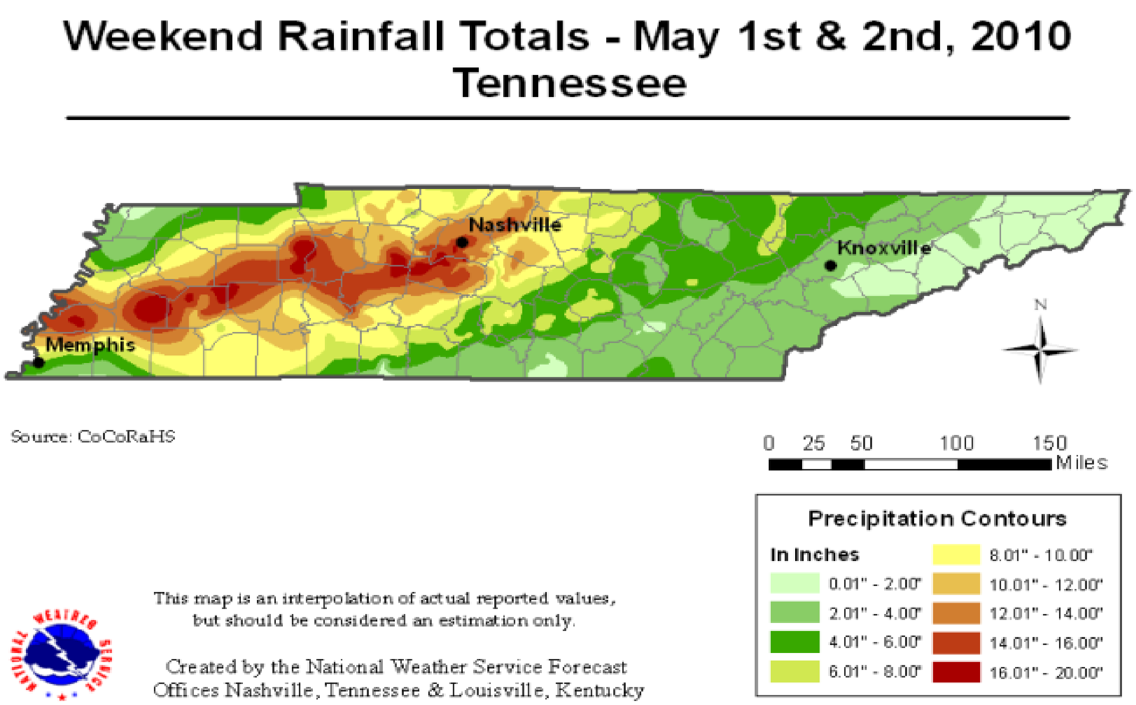

Figure 3. Rainfall Totals, May 1 – 2, 2010.

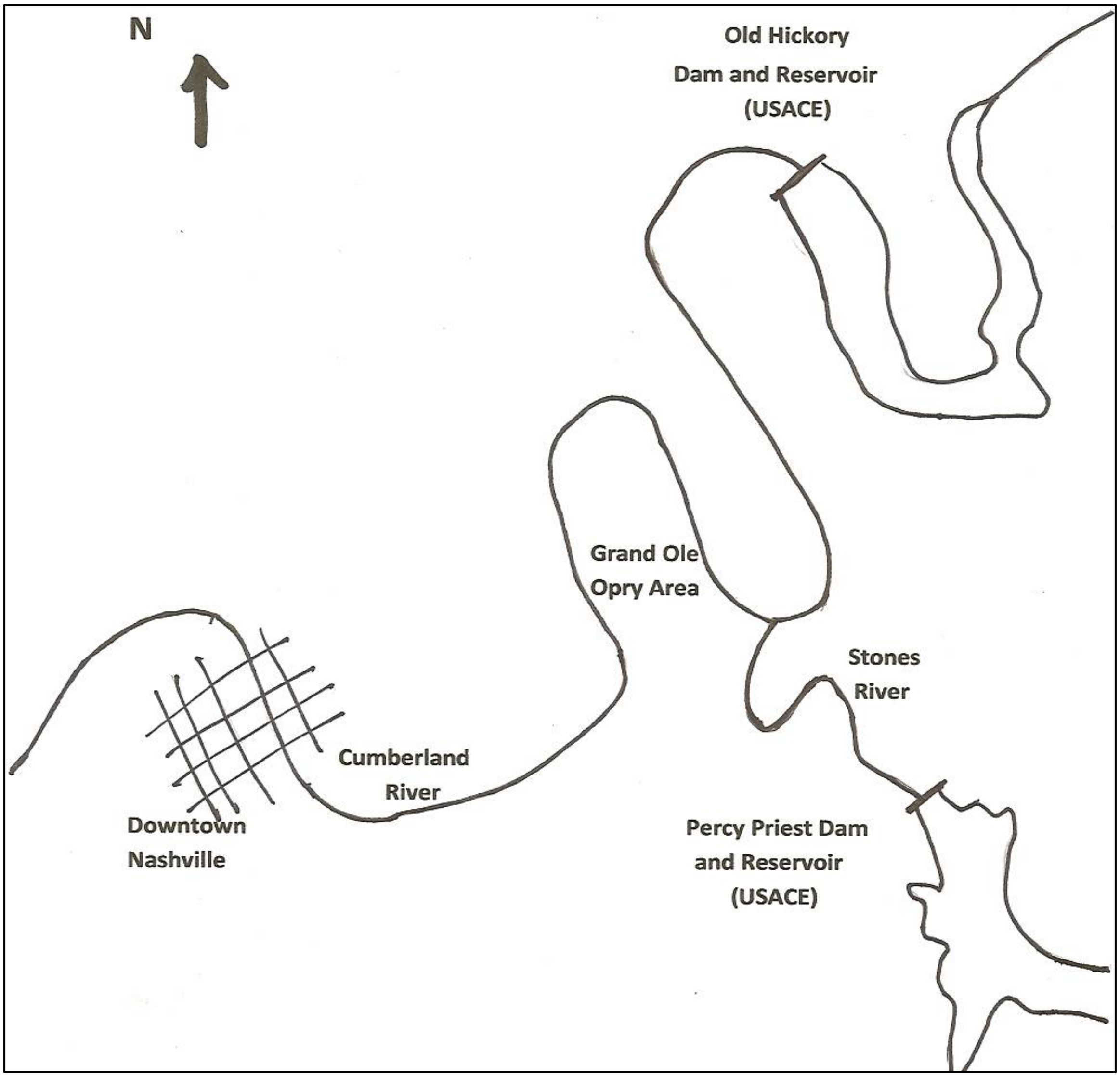

Figure 4. Cumberland River in the Nashville Area

Table 1. Cost and Damage to Nashville/Davidson County "Metro" Facilities

Emergency Services	$10.5M
Debris Removal	$13.3M
Buildings	$12.8M
Electrical and Energy Systems	$13.5M
Fleet Management (Vehicles)	$0.8M
Parks and Recreation Facilities	$1.8M
Roads	$4.5M
Schools	$1.9M
Sewer Systems	$48.1M
Storm Drains	$3.4M
Water Systems	$6.9M
Total	$117.5M

DECISION MAKING UNCERTAINTIES

There were a number of decision making uncertainties that resulted in confusion and a lack of awareness of the severity and the aerial extent of the flood. NWS Weather Forecast Offices (WFO) issued flash flood watches on Thursday and Friday, April 29 and 30, 2010, and the WFO in Nashville issued numerous flash flood warnings on Saturday, May 1, 2010. Nashville area media broadcast 24-hour flood coverage over the weekend. The wording of the coverage, however, was such that the severity of the anticipated flood was underestimated by residents and emergency managers.

Staffs of the NWS, USACE, and USGS were pushed to the limit during the flood event, as were first responders, local officials, and local emergency managers. All agencies were in a reactive mode which lasted until Tuesday, May 4, 2010, when water levels had significantly receded.

There were numerous revisions to the forecasted flood peak in the Cumberland River. On Sunday Morning, May 2, the WFO in Nashville predicted a crest at Nashville to be 41.9 feet that evening, exceeding the flood stage of 40.0 feet. Later that day the NWS and USACE did not effectively communicate on releases of USACE reservoirs on the Cumberland River upstream of Nashville. This led to inaccurate flood crest forecasts for the Cumberland River.

Understandably, USACE personnel were preoccupied with preventing damage to structures and dam failures. The forecasted flood crest was rapidly exceeded and reached the major flood stage of 45.0 feet by 4 pm Sunday afternoon. Updated forecasts throughout the day and evening were for a flood crest of 48.0 feet, 50.3 feet, and 51.5 feet. The river peaked at 51.86 feet on Monday, May 3 at approximately 6 pm.

Despite the many flood watches and warnings issued by the WFO in Nashville, many residents did not understand that the flood would affect them, and could not relate to the specific locations that would be flooded. The local Office of Emergency Services noted that the NWS forecasts for the Cumberland River were lagging behind the actual river levels.

In January 2011 the NWS issued a Service Assessment on the Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010. The assessment provided seventeen findings and recommendations for improving services of the NWS and the need for improving communications between the NWS, the USACE, the USGS, and the Ohio River Forecast Center (OHRFC). The key findings are:

1. Coordination and effective communication between the NWS and the USACE and the USGS was lacking at critical times during the flood event. This undermined key forecasts, in particular on the Cumberland River at Nashville.

2. Effective communication was hampered by a long-term working relationship deficient in a comprehensive understanding of each agency's operational procedures, forecast processes, and critical data needs, especially during non-routine events.

3. Pre-event coordination was proactive. Weather forecasts were sufficiently accurate to alert federal partners and other relevant organizations to the elevated risk for serious flooding in the region during the weekend of May 1-2, 2010. The NWS and other federal agencies responded by planning increased staffing levels.

4. Despite pre-event actions, the increased staffing during the flood event at the two NWS offices most impacted, WFO Nashville and OHRFC, was not sustained consistently at levels required to respond comprehensively to the extreme flooding.

5. Many people did not respond to NWS warnings because the warnings were not tone-alerted via the Emergency Alert System, were not worded in such a manner that adequately reflected the urgency of the situation, or because the warning were not specific enough to cause listeners to believe the flooding would impact their location. Some people failed to receive warnings, or chose to disregard warnings that aired on television.

The key recommendations are as follows:

1. The NWS should engage in additional interactions and exercises with USACE and USGS. Results of these efforts should be a clear understanding of the operating needs and procedures of each agency during routine and extreme events, the creation of quality long-term relationships, and ensuring open and effective communication.

2. OHRFC should develop a list of data exchange processes that can be automated. The list should be provided to USACE and USGS. Candidates for automation should include updated headwater/tailwater conditions and real-time water release data for USACE.

3. The NWS should support field office staffing for potentially high impact events by implementing proven pre-event and event staffing models successfully employed by other field offices.

4. NWS, USACE, and USGS should expand current inundation mapping initiatives in major populated and flood-prone areas.

EARTHQUAKE CONCERNS

There is also potential for a major earthquake in Tennessee which could cause a much more severe disaster than the flood of 2010. Earthquakes on the New Madrid Fault struck the area in 1811 and 1812 and were estimated to be of equal force as the San Francisco earthquake of 1906, which exceeded a magnitude of 7.0 on the Richter scale. An earthquake of this magnitude could damage over 700,000 buildings and cause damage in excess of $300 billion. Deaths could exceed 2000, and power grids, natural gas pipelines, and other infrastructure could be impacted for weeks to months. Emergency management agencies have educated the public and made contingency plans, and states in the area have adopted better building codes.

To recognize the 200th anniversary of the quakes, the Federal Emergency Management Agency and eight states conducted the National Level Exercise 2011 in May. On the state level, the Tennessee Emergency Management Agency and officials with, among others, the Federal Emergency Management Agency, the USACE, the Department of Homeland Security, the U.S. Earthquake Consortium, the Environmental Protection Agency, the Tennessee Department of Transportation and FedEx met in downtown Nashville for a Resource Allocation Workshop.

CONCLUSION

The Tennessee flood of May 2010 caused over $2 billion in damages, and the death of 26 people. Up to 20 inches of rain fell in less than two days, estimated to be a one in one thousand year event. In addition to many tributary streams flooding, the Cumberland River at Nashville crested at almost 12 feet above flood level.

Breakdowns in communications between the NWS, the USACE, the USGS, and state and local emergency management agencies resulted in numerous revisions to the forecasted flood peak, and a lack of public awareness of the urgency of the situation and of the extent of the area that would be impacted. A Service Assessment prepared by the NWS provided seventeen findings and recommendations for improving services of the NWS and the need for improving communications between the NWS, the USACE, the USGS, and the Ohio OHRFC. A need to update flood forecasting models was also identified.

As devastating as the flood of 2010 was, there is the potential for a major earthquake in Tennessee, which could cause a much more severe disaster.

Lessons learned should assist irrigation and water districts in preparing for and responding to emergency situations.

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WATER USE AND URBANIZATION: THE TRUCKEE RIVER OPERATING AGREEMENT

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Therese A. Ure[2]
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ABSTRACT

In September 2008, the United States, the Pyramid Lake Paiute Indian Tribe, the States of Nevada and California and other parties executed the Truckee River Operating Agreement ("TROA"). Once implemented, TROA will alter the management and operation of the Truckee River system, including Lake Tahoe in California to Pyramid Lake in Nevada, various tributary reservoirs, and the diversion of Newlands Project reclamation water from the Truckee River to the Carson River basin.

TROA is, in part, a response to changed conditions in the area.[4] Since the time that current management and operation criteria were set, populations and land uses have changed. New federal regulations have emerged, such as the Endangered Species Act, and environmental interests have grown. Urban water uses have started to take center stage over the agricultural uses which were once predominant in the area. The parties to TROA are seeking to modify management and operation criteria accordingly.

Implementation of TROA is proving to be challenging. TROA will affect prior agreements and water right decrees, thus necessitating the inclusion and cooperation of all parties to the prior agreements. The relevant decrees will likewise need to be reopened in order to accomplish the proposed modifications.

This paper first summarizes the lengthy and contentious history leading up to TROA. Next, it examines TROA's provisions and current status. Then it considers urbanization in the Truckee and Carson River Basins and the effects of changing demographics and land use patterns. Finally, this paper concludes that although TROA's effects are not yet clear, what is clear is that land and water uses in the basin are forever changing, and the parties must work together to allocate the finite supply of water to those uses.

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[4] Truckee River Operating Agreement R-2 (September 2008) (hereinafter "TROA"), available at: http://www.usbr.gov/mp/troa/final/troa_final_09-08_full.pdf, last viewed June 21, 2011.

INTRODUCTION

Nevada is the driest state in the United States. Total precipitation in Nevada averages less than ten inches annually.[5] However, Nevada is also one of the fastest-growing states in the nation. Between the years 2000 and 2010, Nevada's population increased by 35.1 percent while the total population increase throughout the United States was 9.7 percent.[6] Because of the limited water resources in Nevada, and because of the booming population growth in the State, water control and management projects are incredibly important for providing stable and reliable supplies of water to Nevada's residents.

The Truckee River and the Carson River are two major interstate rivers that traverse the borders of Northern California and Northern Nevada, the Truckee River situated to the north and the Carson River to the south. The Truckee River begins at Lake Tahoe that is also split by the states' border, flows through the cities of Reno and Sparks, and terminates in Pyramid Lake, within the Pyramid Lake Paiute Indian Reservation. Several diversions exist along the Truckee River that appropriate water to beneficial uses. The Newlands Project diversion is on the lower Truckee River and diverts water via the Truckee-Carson Canal starting at Derby Dam to Lahontan Reservoir which lies on the Carson River system. From Lahontan Lake, the water flows to the city of Fallon, the Newlands Project and the Stillwater National Wildlife Refuge.[7]

Water use from the Truckee River, the Carson River and the relevant reservoirs and tributaries has become extremely complicated. Interested parties to the waters include California, Nevada, the United States, Indian tribes, individual water right holders, cities and counties in California and Nevada, environmentalists, various water and electricity providers and more. The various parties have divergent interests, such as agricultural, municipal, industrial, domestic, aesthetic and environmental uses. Despite a growing population and divergent interests in the area, the amount of water available each season though variable, is finite. This fact has led to over a century of disputes, decrees, agreements and regulations.

[5] U.S. Department of the Interior, U.S. Geological Survey, Nevada Water Science Center, *Surface-Water Information and Data*, available at: http://nevada.usgs.gov/water/infodata/surfacewater.htm, last viewed June 21, 2011.

[6] U.S. Census Bureau, State & County QuickFacts, *Nevada*, available at: http://quickfacts.census.gov/qfd/states/32000.html, last viewed June 21, 2011.

[7] See Figure 1.

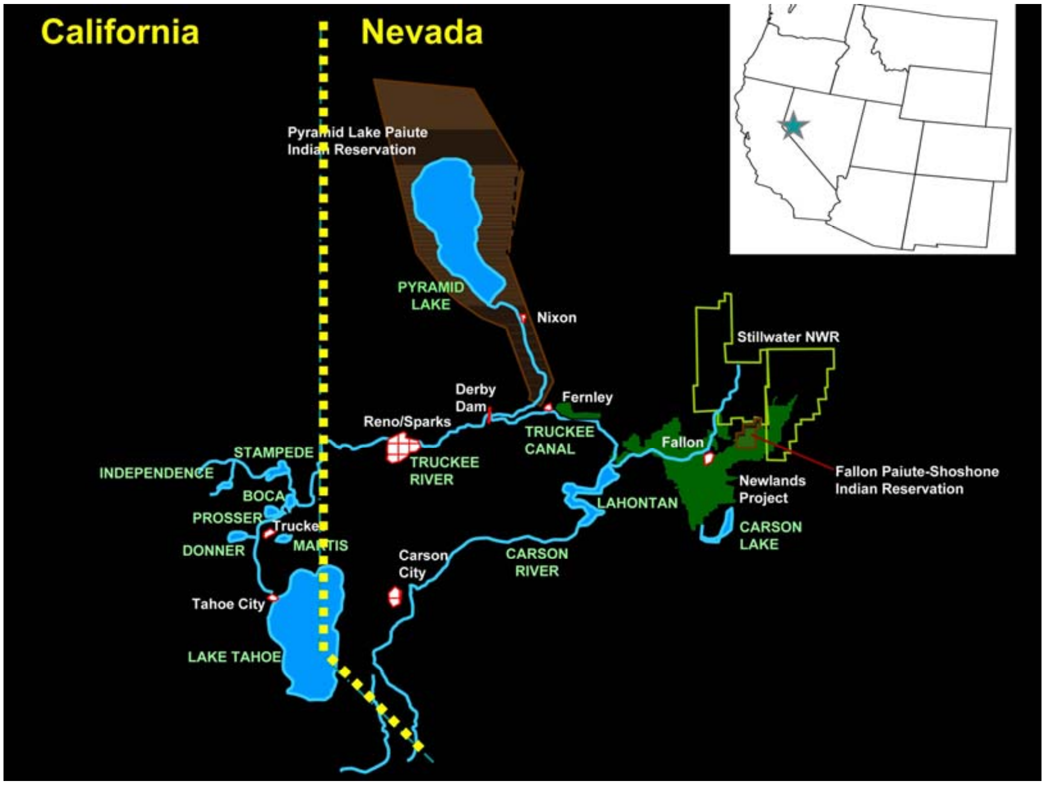

Figure 1
Available at: http://www.cwemf.org/Asilomar/RiverWareTROAModel.pdf

DISCUSSION

<u>History of TROA</u>

In the late 1800s, rapid growth in the Truckee River Basin resulted in increasing water diversions by settlers.[8] However, without large water storage projects, there were frequent water deficiencies in the late months of the irrigation season.[9] In 1902, Congress passed the National Reclamation Act, which permitted the Bureau of Reclamation to construct irrigation projects in the western United States to "reclaim" the West's arid lands and to make those lands suitable for settlement and agriculture by constructing large water infrastructure projects.[10] The Newlands Project, originally named the

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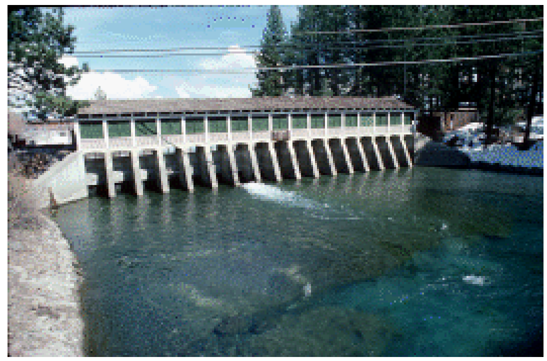
[8] U.S. Bureau of Reclamation, *Newlands Project*, available at: http://www.usbr.gov/projects/Project.jsp?proj_Name=Newlands+Project, last visited June 21, 2011.

[9] *Id*.

[10] Nevada Department of Conservation and Natural Resources, Division of Water Planning, *Truckee River Chronology: A Chronological History of Lake Tahoe and the Truckee River and Related Water Issues*, Part 3 (hereinafter "Truckee River Chronology Part 3") 2, available at: http://images.water.nv.gov/images/publications/River%20Chronologies/Truckee%20River%20Chronology.pdf, last visited June 21, 2011. See also, Act of June 17, 1902 ("Reclamation Act"), 32 Stat. 388, 43 USC 391, Pub. L. 57-161.

Truckee-Carson Irrigation Project, was the first reclamation project to be completed.[11] Currently, the Newlands Project provides water to the Nevada counties of Churchill, Lyon, Storey, and Washoe from the Truckee River and through the Derby Dam and Truckee Canal to the Carson River. The Derby Dam was completed on May 20, 1905, and water began flowing through the Truckee Canal on June 17, 1905.[12]



Lake Tahoe Dam
Available at: http://www.usbr.gov/projects/Project.jsp?proj_Name=Newlands+Project

At the time the Newlands Project was constructed, the Truckee River General Electric Company (presently the Sierra Pacific Power Company) owned Lake Tahoe Dam and surrounding property.[13] The Truckee River General Electric Company executed an agreement with the Floriston Land and Power Company and the Floriston Pulp and Paper Company in 1908 which required that there be a mean flow of water in the Truckee River at Floriston, California (near the California-Nevada border) of 500 cubic feet per second ("cfs") from March 1 through September 30, and 400 cfs between October 1 through the last day of February, annually.[14] These are called the "Floriston rates." Pursuant to the agreement, if flow rates are not being met, then the Truckee River General Electric Company must release water from Lake Tahoe, if possible, to sustain the agreed-upon rates.[15]

Soon after the Derby Dam and Truckee Canal went into operation, it became clear that the supply of water for the Newlands Project was inadequate and inconsistent. Periodic drought and flood conditions necessitated the building of more storage and overflow reservoirs. Today, the main water control and storage features of the Newlands Project include:

- Lake Tahoe Dam (owned by Sierra Pacific with an easement to the United States)
- Derby Dam & the Truckee Canal
- Lahontan Dam & Reservoir
- Boca Dam & Reservoir

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[11] *Id*.

[12] *Id*. at 4-5.

[13] *Id*. The United States took over the Lake Tahoe Dam in 1915 pursuant to a court order based on a condemnation proceeding brought by the federal government. The United States paid $139,500 as consideration to the Truckee River General Electric Company for an easement to operate the dam. The company retained the underlying ownership to the dam. See U.S. v. Truckee River General Electric Company, Civ. No. S-643-LKK (E.D. Cal. 1915).

[14] *Id*. at 7.

[15] *Id*.

- Martis Creek Reservoir (owned by the United States and operated by the Army Corps of Engineers for flood control)

The Army Corps of Engineers also undertook several projects after the Flood Control Act of 1954 was passed to reduce flooding along the Truckee River.[16] Finally, there are two private reservoirs along the Truckee River in California::

- Donner Lake
- Independence Lake & Dam

On March 30, 1913, the Bureau of Reclamation brought suit against all upstream users on the Truckee River to comprehensively adjudicate the water rights to the river.[17] The case took over thirty years to adjudicate, resulting in what is known as the "1944 Orr Ditch Decree."[18] In the meantime, the United States, the Truckee-Carson Irrigation District ("TCID")[19] and the Sierra Pacific Power Company (formerly the Truckee River General Electric Company) entered into the "1935 Truckee River Agreement" which provided for conservation and control of flood waters, set the natural rim and storage in Lake Tahoe, provided for additional storage in other reservoirs and incorporated the Floriston rates.[20] The 1944 Orr Ditch Decree incorporated the Truckee River Agreement, and granted the Pyramid Lake Paiute Indian Tribe ("PLPT") the two most senior water rights on the river, followed in priority by Sierra Pacific's water right, and then Newlands Project reclamation rights.[21]

In 1955 Congress passed a law which allowed California and Nevada to enter into an interstate compact to allocate the waters of the Truckee River, Carson River, Walker River, Lake Tahoe, and all tributaries between the two states.[22] The California-Nevada Interstate Compact was approved by California in September, 1970, and by Nevada in March, 1971.[23] Although Congress never ratified the compact, many of its terms were included in a settlement agreement reached in 1990, discussed *infra*, and both states implemented the compact through state legislation.[24]

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[16] *Id*. at 21.

[17] United States v. Orr Ditch Water Company, et al., Equity No. A.3 (D. Nev. 1944).

[18] Truckee River Chronology Part 3 at 10.

[19] TCID took over all management and repayment aspects of the Newlands Project in 1927 through a contract with the United States. *Id*. at 13-14.

[20] *Id*. at 16.

[21] *Id*. at 19. The Tribe's priority date was set as December 8, 1859 with a total diversion amount of 30,000 acre-feet for irrigation. Sierra Pacific was granted a right to use 40 cubic feet per second, which is approximately 29,000 acre-feet annually, for domestic purposes in the Reno and Sparks metropolitan area. Finally, the United States' priority was set as July 2, 1902 for reclamation rights at a maximum of 1,500 cfs on 74,500 acres of farmland. *Id*.

[22] Truckee River Chronology Part 3 at 22.

[23] *Id*. at 28.

[24] *Id* at 27-28. *See also*, Truckee-Carson-Pyramid Lake Water Settlement Act, 104 Stat. 3289, Title II, Pub. L. 101-618, (November 16, 1990).

In order to provide additional water storage along the Truckee River, Congress authorized the Bureau of Reclamation's Washoe Project in 1956. Initially, the Washoe Project was intended to serve agricultural interests and power development, however, certain features of the project were later dedicated to Pyramid Lake for fishery purposes.[25] The Carson-Truckee Water Conservancy District was created to manage water contracting and repayment for project costs.[26] The projects built under the Washoe Project include the following:

- Prosser Creek Dam & Reservoir
- Marble Bluff Dam and Pyramid Lake Fishway
- Stampede Dam & Reservoir

Under the 1959 Tahoe-Prosser Exchange Agreement, when minimum in-stream flows are released in summer and winter, but when such flows are not necessary to fulfill the Floriston rates, then that amount of water, called "exchange water," would be stored at Prosser Reservoir for release at a later time.[27] This allowed for additional flows in the Truckee River between Lake Tahoe and Prosser Reservoir for fishery and recreation purposes. In 1961, the United States filed suit to incorporate the agreement into the 1915 Truckee River General Electric Company decree.[28]

In 1967, the Secretary of the Interior issued Newlands Project regulations known as the Operating Criteria and Procedures ("OCAP").[29] The OCAP required Newlands Project water users to conserve as much water as possible and to take more water from the Carson River rather than from the Truckee River through the Truckee Canal.[30] The OCAP also restated the total irrigated acreage under the Newlands Project and the total water allocation (74,500 acres and a total of 406,000 acre-feet), as agreed upon by the Bureau of Reclamation and TCID under the parties' original contract in 1918.[31]

In response to OCAP, the PLPT brought several legal suits.[32] The suits resulted in a judgment known as the "Gesell Opinion," which set new operating criteria for the Newlands Project. The Gesell Opinion required stepped-down total diversions for the Newlands Project from 406,000 acre-feet to 288,129 acre-feet over the course of more than a decade. The court issued its ruling based on its findings that more water was being

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[25] *Id*. at 22. See discussion at footnotes 39-40 and accompanying text *infra*, showing that water from Stampede Dam and Reservoir was later rededicated to Pyramid Lake for the purpose of sustaining the cui-ui fish and Lahontan cutthroat trout.

[26] *Id*.

[27] *Id*. at 23.

[28] *Id*. at 24.

[29] *Id*. at 26.

[30] *Id*.

[31] *Id*.

[32] *Id*. at 30.

used than authorized on certain types of lands (4.5 acre-feet on bench lands and 3.5 on bottom lands), that there were inefficiencies within the Newlands Project system, and that TCID was not complying with certain interim OCAPs.[33] In 1973, a new OCAP was ordered by the Gesell court, and the Secretary of the Interior, Rogers Morton, notified TCID that excessive diversions over and above that set by the 1973 OCAP and Gesell Opinion would have to be returned to Pyramid Lake. However, between the time of notice and the year 1988, the amount of excessive diversions grew.[34] The recoupment of excess diversions is being resolved in litigation on current remand to the Nevada Federal District Court.

In 1976, the Pyramid Lake Paiute Indian Tribe brought suit to obtain water rights to sustain Cui-ui fish and Lahontan Cutthroat Trout populations in Pyramid Lake.[35] The 1944 Orr Ditch Decree only allocated water to the Indian reservation for irrigation purposes. By court decree (and as part of the Pyramid Lake Paiute Tribe Settlement with the United States for failure of the United States' attorneys to assert reserved rights for the Tribe in the Orr Adjudication) Stampede Reservoir, a feature of the Washoe Project, was changed to reserve it for the sole use of benefiting the Pyramid Lake fishery, thus changing the original purpose of Stampede Dam and Reservoir, which was to provide water for agricultural purposes in the Newlands Project farmlands.[36]

Pyramid Lake
Available at: http://ndep.nv.gov/photo/pyramid_lake2.htm

From the 1970's to 1990, litigation continued concerning Indian reserved water rights, water for municipal and industrial purposes stored in federal reservoirs, the allocation of water between Nevada and California, and

[33] *Id*.

[34] *Id*. at 31-32.

[35] Id. at 37. See also, Carson-Truckee Water Conservation District v. Watt, 537 F.Supp. 106 (D.Nev. 1982), affirmed 741 F.2d 257 (9th Cir. 1984).

[36] *Id*.

water rights for irrigation.[37] Thus, it became clear to Congress that a regional settlement of all issues was necessary. On November 16, 1990, Congress enacted the Truckee-Carson-Pyramid Lake Water Settlement Act ("1990 Settlement Act") commonly referred to as Public Law 101-618.[38]

Section 204 of the Settlement Act provides for an interstate allocation of Lake Tahoe and Truckee River waters between California and Nevada similar to that agreed upon in the California-Nevada Interstate Compact.[39] The section also confirms the allocation of the Carson River between the states,[40] as decided by the Alpine Decree.[41]

Section 205(a) of the Settlement Act directs the Secretary of the Interior to negotiate an operating agreement for the Truckee River reservoirs that provides for satisfaction of water rights under the 1944 Orr Ditch Decree, municipal and industrial water storage and drought prevention, and water for fisheries.[42] This mandate resulted in the TROA, and the Settlement Agreement is "contingent on completion of the TROA."[43]

Section 209 of the Settlement Act provides that the Secretary of the Interior shall not implement any provision of the legislation in a manner that would increase diversion of the Truckee River water to the Newlands Project over those allowed under the applicable operating criteria and procedures or that would conflict with applicable court decrees.[44] It further imparts the Secretary with the ability to cancel repayment obligations owed by TCID to the Bureau of Reclamation if TCID agrees to collect the repayment obligations and use the collected funds for water conservation measures.[45] However, those provisions shall not become effective unless and until TCID has entered into a settlement agreement with the Secretary concerning claims for recoupment of water diverted in excess of permitted amounts,[46] and Nevada sets aside at least $4,000,000 for use in implementing water conservation measures.[47]

Subsequent to the ratification of the 1990 Settlement Act, the United States, Reno and Sparks, Nevada, Washoe County, the Pyramid Lake Paiute Indian Tribe and the State of

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[37] Department of the Interior, Bureau of Reclamation, *Operation of the Truckee River and Other Reservoirs* (hereinafter "TROA Proposed Rule"), 40 CFR 419, 73 Fed. Reg. 179, 53181 (September 15, 2008).

[38] Truckee-Carson-Pyramid Lake Water Settlement Act, 104 Stat. 3289, Title II, Pub. L. 101-618, (November 16, 1990).

[39] TROA Proposed Rule at 53182; Truckee-Carson-Pyramid Lake Water Settlement Act.

[40] *Id*.

[41] U.S. v. Alpine Land and Reservoir Company, et al., Civ. No. D-183 BRT (1980).

[42] TROA Proposed Rule at 53182; Truckee-Carson-Pyramid Lake Water Settlement Act.

[43] Cosens, *infra* note 64 at 1283.

[44] TROA Proposed Rule at 53182; Truckee-Carson-Pyramid Lake Water Settlement Act.

[45] *Id*.

[46] Repayment and recoupment amounts are currently in litigation on remand from the Ninth Circuit Court of Appeals to the Nevada Federal District Court.

[47] *Id*.

Nevada executed the 1996 Truckee River Water Quality Settlement Agreement.[48] The agreement creates a program under which the United States and the cities of Reno and Sparks can purchase and dedicate water rights for in-stream purposes, thereby improving water quality in the Truckee River.[49]

The Truckee River Operating Agreement ("TROA")

The Department of the Interior, Bureau of Reclamation along with others[50] ("promoting parties"), have opined and identified several positive effects caused by TROA, including: 1) improved conditions for threatened and endangered species in the river system, 2) increased municipal and industrial water supplies for drought protection in Reno and Sparks, Nevada, 3) improved water quality in the Truckee River, especially downstream from the Derby Dam, 4) enhanced stream flows in the Truckee River for better recreational opportunities, and 5) established procedures for implementing the allocation of waters of the Truckee River system between California and Nevada.[51]

In general the promoting parties suggest, TROA will provide coordinated management rules and operating procedures for the reservoirs along the Truckee River, including storage and release provisions in order to maintain flow rates, prepare for droughts, and better serve the sometimes diverging interests in the river such as fisheries, environmental protection, municipal water supplies, power generation, and agriculture.

TROA provides that the Truckee River reservoirs will continue to be operated to give effect to existing water rights under the 1944 Orr Ditch Decree, and the previous agreements enacted by the parties. However, those opposing TROA, including many Newlands Project water users and TCID, argue that while the federal mandate states that TROA should not affect any existing rights, the operating criteria under TROA could prove opposite. In fact, TCID as administratorr of the Newlands Project was not afforded any opportunity to actively participate in the creation of TROA. If TROA truly will not affect any existing water rights, then the promoting parties should have had no issue with TCID's participation.

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[48] TROA Proposed Rule at 53182.

[49] *Id*.

[50] The proponents of TROA are generally referred to herein as the "promoting parties." The promoting parties include a combination of two groups: 1) **The TROA Signatory Parties** who signed TROA are State of California, Truckee Meadows Water Authority, United States, Pyramid Lake Paiute Tribe, Washoe County Water Conservation District, State of Nevada, City of Reno, County of Washoe; City of Sparks, City of Fernley, Carson-Truckee Water Conservancy District, Sierra Valley Mutual Water Company, Truckee Donner Public Utility District, North Tahoe Public Utility District, Placer County Water Agency, and Sierra Pacific Power Company; and 2) **The TROA Parties** pursuing the opening of the Decree in Federal Court seeking to adopt TROA, collectively are Truckee Meadows Water Authority, United States, Pyramid Lake Paiute Tribe, Washoe County Water Conservation District, State of Nevada, and interveners City of Fernley and the State of California. The "TROA Parties" are sometimes referred to as the TROA Moving Parties.

[51] *Id*. at 53180.

The Bureau of Reclamation has identified several areas which will be different under TROA than they are currently. *First*, TROA establishes "credit water."[52] Under Article Seven of TROA, a water user may keep some or all of the water they are entitled to use in storage as credit water in the Truckee River reservoirs.[53] However, the water user will still need to execute a storage contract with the reservoir owner in order to do so.[54] For example, two of the categories of credit water are M&I Credit Water, to be used as drought supply, and Fish Credit Water, to be used for the benefit of the Pyramid Lake fishery.[55] TROA sets up a priority system for the different types of water credits.[56]

Second, Article Eight of TROA allows for the exchange of credit water among different Truckee River reservoirs.[57] The Bureau of Reclamation believes that the water exchange program will increase flexibility and facilitate "more efficient use of the existing available water supply to more effectively serve the many, and often competing, beneficial uses."[58]

Third, TROA establishes a dispute resolution mechanism. Article Two of TROA creates an Administrator to manage TROA's specifications and a Special Hearing Officer to conduct dispute resolution.[59] However, the Federal Water Master who was appointed under the 1944 Orr Ditch Decree to make sure that water rights under the decree are satisfied, will retain those responsibilities once TROA is implemented.[60]

Currently, the supporting parties to TROA are working towards implementation. State storage rights, in California and Nevada, must be transferred and reallocated and prior court decrees must be reopened and modified. These supporting parties to TROA include the United States, the Pyramid Lake Paiute Tribe of Indians, the states of Nevada and California, and various cities, municipalities, water associations, and a few individual water right holders.

Those opposing TROA argue that the establishment of "credit water" is contrary to the original Truckee River Agreement and in violation of the 1944 Orr Ditch Decree. If the water is moved to "credit water," or is transferred from agriculture to M&I, there is less water in the system available for diversion into the Newlands Project. The opposition also is concerned that the movement of water from the downstream Newland Project to the upstream storage reservoirs will affect the hydraulic cycles, thus creating less recharge in the Project area. Studies show that this recharge is an integral part of the

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[52] *Id*. at 53182.

[53] *Id*.

[54] *Id*.

[55] *Id*.

[56] *Id*.

[57] *Id*. at 53183.

[58] *Id*.

[59] *Id*.

[60] *Id*.

ground water system assisting to lower total dissolved solids ("TDS") levels in the Newlands Project areas.

In addition, this transfer will likely cause TCID to suffer damages in that the Project was built for drastically more agricultural acres than it is now serving. The ratio of water in the system, as built, to create efficiencies is different than the ratio for efficiencies in the same system with less water and less acres to serve. In the Newlands Project, the amount of seepage and conveyance loss will likely be the same no matter if the project serves 100 or 1000 acres. The water still must go down each canal to serve the water users at the end of the system. Thus efficiencies will decrease and Decreed water rights of use holders will be harmed.

Finally, there are many other parties whose voices are yet to be heard.

Urbanization and its Effects

At the beginning of the Twentieth Century, approximately half the population in the western United States was employed in farming and ranching, but today that figure is less than five percent.[61] Thus, urban demands now compete with agricultural demands for water resources. In addition, municipalities are tasked with the duty of supplying residents with water supplies even in times of water shortage,[62] and thus urban water demands are less flexible than agricultural demands.[63]

The Orr Ditch Decree allocated Sierra Pacific Power Company a right to use 40 cubic feet per second, which is approximately 29,000 acre-feet annually, for domestic purposes in the Reno and Sparks metropolitan area.[64] However, demand for municipal and industrial water in 2008 was 61,000 acre-feet annually.[65] The urban population in the area is continuously growing, and thus the amount of water required to satisfy municipal and industrial use demands will continue to rise. Between the years 1960 and 1990, domestic withdrawals of water more than doubled in the West.[66]

In order to supplement its municipal and industrial water supplies, Sierra Pacific has turned to groundwater sources and the purchase of agricultural lands with appurtenant water rights.[67] As of 2008, 40,910 acre-feet of agricultural water rights had been

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[61] Cosens, Barbara, *Farmers, Fish, Tribal Power, and Poker; Reallocating Water in the Truckee River Basin, Nevada and California*, 14 Hastings W.Nw. J. Envt'l L. & Pol'y 1243, 1273-74 (2008). See also, Tarlock, A. Dan and Van de Wetering, Sarah B., *Growth Management and Western Water Law: From Urban Oases to Archipelagos*, 14 Hastings W.Nw. J. Envt'l L. & Pol'y 983, 991 (2008).

[62] Tarlock, *supra* note 64 at 998.

[63] Cosens, *supra* note 64 at 1277 and 1285.

[64] See footnote 20 and accompanying text.

[65] Cosens, *supra* footnote 64 at 1274.

[66] Tarlock, *supra* footnote 64 at 992.

[67] Cosens, *supra* footnote 64 at 1276.

purchased and transferred to municipal and industrial purposes,[68] and 12,340 acre-feet of groundwater had been developed.[69]

The transfer of agricultural lands and appurtenant water rights to municipal purposes highlights the land use transformation that is taking shape in the West. As urban populations increase and agricultural populations decline, water rights are being transferred away from agricultural uses and towards municipal ones. Agricultural communities are in decline, and the effects of this trend will be widespread since urban dwellers rely on agricultural production and because agriculture is such an important part of our nation's heritage. The nation's reliance on foreign agriculture products will only increase.

TROA attempts to provide municipalities the ability to store water in federal reservoirs in order to provide cities with reliable water supplies even in times of drought. Perhaps TROA will slow the need of area cities to buy up additional agricultural lands and water rights. However, this remains to be seen.

Conclusions

The Truckee River Basin is located in one of the driest places in the United States. Despite that fact, it is also one of the fastest growing areas of the country. Residents continue to flock to the area, causing urban centers to boom. However, rural areas are on the decline and many agricultural lands are being converted to municipal uses, along with their highly-prized appurtenant water rights.

As to TROA, state water rights must be transferred, private parties must consent to use of certain reservoirs for public purposes, and court decrees must be opened and modified.

It is not yet clear whether TROA, if adopted by the federal court, will accomplish its stated goals. What is clear is that land uses, water uses, and demographics in the Truckee River Basin are continuing to change. The Basin, which was once dominated by agricultural interests, is now feeling the pressure of urban, fishery and environmental interests. The annual supply of water is finite, and now the parties must struggle to satisfy those divergent needs. There will be winners and losers.

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68 This transfer of agricultural water rights to municipal rights has caused severe degradation of the land, effectively drying up the area without the establishment of native vegetation, thus creating land that has no value.

69 *Id.*

Cosens, Barbara, *Farmers, Fish, Tribal Power, and Poker; Reallocating Water in the Truckee River Basin, Nevada and California*, 14 Hastings W.Nw. J. Envt'l L. & Pol'y 1243, 1273-74 (2008).

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COLORADO RIVER SALINITY DAMAGE MODEL

Charles L. Borda[1]

ABSTRACT

The Colorado River Salinity Control Program uses a model, Salinity Damage Economic Model that assesses the current and future economic damages in the Lower Colorado River Basin based on salinity levels at the Hoover, Parker and Imperial Dams. The model is also used to estimate the potential benefits of implementing salinity control projects in the Upper Colorado Basin by estimating the reduction in salinity related costs that would be incurred in the Lower Colorado Basin.

This model is used in conjunction with the Colorado River Simulation System (CRSS). The CRSS program is used to evaluate the impact of water development and Salinity Control on the Colorado River. The TDS levels estimated from the CRSS program for the three Lower Basin Dams are used as input to the Salinity Damage Economic Model. The damage model then estimates the salinity related damages in agricultural production, residential, commercial, industrial, and utility water use. The model also estimates the costs related to meeting local and regional water quality standards for groundwater and recycled water in portions of the Lower Basin.

The model attempts to estimate the impacts on irrigated agricultural production in the lower Colorado River Basin due to high salinity levels in the Colorado River. The model uses average salinity crop yield functions to estimate a per acre crop yield at a given TDS level. The estimated per acre crop yield is multiplied by the number of crop acres and the per unit crop price to derive the gross crop value at the given TDS level. This method is applied at different TDS levels to estimate the economic impact of lower or higher salinity levels in the Colorado River.

INTRODUCTION

The Salinity Damage Model estimates the quantitative damages that are incurred in the metropolitan and agricultural areas in the lower Colorado Basin that receive Colorado River water. The model estimates the impacts from salinity levels greater than 500 TDS on household water using appliances, damages in the commercial sector, industrial sector, water utilities, and agricultural crop revenues. It also estimates the additional costs related to meeting state wide water quality standards for grown water and recycled water use (MWD service area).

The model only estimates damages that can be quantified at the present time. For example, the model does not account for on farm management costs related to high salinity levels or the costs associated the replacement of low tolerant crops to high tolerant crops in the Lower Basin agricultural areas. Further research is being conducted

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try and identifies other areas related to high salinity levels. There has been some initial investigation on the impact of high salinity levels on golf course turf in the southwestern portion of the United States. Currently, Reclamation is in the process of signing a memorandum of understanding with Metropolitan Water District of Southern California (MWD) to update and enhance the MWD portion of the salinity damage model. This cooperative effort hopes to identify other salinity damages that are not currently identified with the present model. Other areas for future research could be in identifying the costs or damages due to salinity contribution to groundwater areas in the southwest and the management costs associated to brine removal.

The salinity damage model was updated from 2005 price levels to 2008 price levels. Population projections were updated also for the Central Arizona metropolitan areas, Las Vegas/Clark County area as well as the communities along the lower portion Colorado River in Nevada, Arizona and California

The Colorado River Salinity Damage Model consists of a number of EXCEL spreadsheets. The initial worksheet displays some overall input data and the summary quantifiable dollar damages by economic sector and primary agricultural and metropolitan areas that receive Colorado River water.

SUMMARY SALINITY INPUT/AND DOLLAR DAMAGE OUTPUT SHEET

The upper portion of this spreadsheet contains the water quality – salinity levels of the lower Colorado River that are measured at Hoover, Parker and Imperial dams. This data can come from actual sampling at these site or projected values can be obtained from the CRSS hydrologic model. Also, this portion of the spreadsheet contains input data for present valuing damages that may occur in the future. The present value data consists of the latest Reclamation planning interest rate, base dollar year, and the projected year the damages are to be calculated.

The remaining portion of this spreadsheet displays the salinity levels and total damages (based on a 500 TDS salinity baseline) for each primary agricultural and metropolitan area that receives Colorado River water. There are six economic sectors; agriculture, households, commercial, water utilities, industrial and policy related (groundwater and recycled water requirements). The agricultural areas currently in the model are Central Arizona Project, Arizona; La Paz County, Arizona; Yuma County, Arizona; Imperial County, California, Riverside County (non MWD), California, and MWD service area (covers all or portions of six southern California counties).
The metropolitan areas currently in the model are: Maricopa County/Phoenix; Pima County/ Tucson; Clark County/Las Vegas; MWD service area; and lower Colorado River communities. Data is being incorporated into the model to include the Yuma, Arizona metropolitan area.

SUMMARY DAMAGE CALCULATION SHEET

In this spreadsheet, the dollar damages from each of the sectors and areas are displayed for the baseline salinity level (500 TDS) and the current or projected salinity levels. It is a rather large spreadsheet because it is linked to all the calculation spreadsheets. For example, the household damages are listed by metropolitan area and by household item for the baseline and current or projected salinity levels. Displaying the damage estimates in this manner aids in identifying particular household items or crops that are impacted by salinity damage functions differently or where salinity levels are higher in a particular area. The differences in dollar damages between the 500 TDS salinity level and the current or projected salinity level is summed by sector and by Lower basin areas. This procedure estimates the current or projected damages which are greater than the damages at the 500 TDS level. To estimate the benefits of the Colorado River Salinity Control Program a series of model runs are made based on concept of “with versus without” additional salinity control projects being implemented in the Program. This application of the model uses salinity levels provided by the CRSS model. The procedure is to estimate the difference in dollar damages from the 500 TDS baseline and TDS levels based on no additional salinity control projects and then estimate the difference in dollar damages based on TDS levels which include additional salinity control projects. With the inclusion of additional projects, salinity levels are less than the “without project” TDS levels and this results in lower dollar damages in the Lower Basin areas. The difference in dollar damages based on the “with versus without” project conditions are identified as the avoided damages or simply the benefits of the Salinity Control program with the implementation of the projects.

To convert the avoided damages (benefits) to per mg/L or ton of salt removed basis, the damages by area are summed for each of numeric criteria diversion site, i.e. Hoover Dam, Parker Dam and Imperial Dam. For Hoover Dam, the difference in total dollar damages for the Las Vegas/ Clark County area are converted to an mg/L basis using the difference in TDS levels for Hoover. This approach is done for the areas that receive Colorado River water at Parker Dam and at Imperial Dam and then summed to a total avoided damage per mg/L for the Lower Basin average. To convert the avoided dollar damages per mg/L to a per ton of salt removal basis, the factor of x,xxx tons per mg/L is used for each diversion point to calculate the avoided damages per ton of salt. Again this is done for each diversion point and then summed to a total benefit value per ton of salt removed from the lower Colorado Basin area.

ADDITIONAL INPUT DATA SHEETS

The next two spreadsheets contain input data. The first spreadsheet contains data to calculate weighted average salinity levels based on different water sources with differing salinity levels for MWD service area and the Central Arizona area. The blending of water sources has a significant impact on the overall water quality that is used by residences, commerce, and industry as well as meeting groundwater and recycled water requirements. The second spreadsheet contains population and number of household projections for each of the metropolitan areas. This data contains the most current and projected population estimates. The population and household data is primarily used in the calculation of household and commercial damages.

DAMAGE CALCULATION SPREADSHEETS

The next six spreadsheets are linked to the other input spreadsheets to actually calculate the salinity damages for each sector and area covered by the model. Salinity crop yield or useful life functions are contained in these spreadsheets, which tie salinity levels to crop yields or product use. Below is brief explanation of each damage spreadsheet:

Household Damage Spreadsheet

This spreadsheet consists of three parts. The first part (Part A) consist of the household items per unit average costs (e.g. water heater cost plus installation), number units per household, and the salinity- useful life functions for each household item considered in the model. There are ten household items that are included in the model. These are; galvanized water pipe systems (older houses), water heaters, faucets, garbage disposals, clothes washers, dishwashers, bottled water, water softeners, water treatment systems, and soaps and detergents. Unit cost prices for each household item were obtained from sources on Internet websites such as Sears, Home Depot, Lowes or supermarkets in the local area. The number of units per household was obtained from the latest Census data for each metropolitan area considered in the model. Salinity useful life functions were developed to estimate the average life of a household appliance based on a given salinity level. Most of the useful life functions were taken from previous salinity research and can be found in the Milliken-Chapman study (1988). MWD had contracted for additional research of bottled water use, water softeners, and water treatment systems and found a relationship between these household items and salinity.

The second part (Part B) of this spreadsheet is the calculation of the useful life and average household costs based on a given salinity level that has been calculated in the input spreadsheet for weighted average salinity values of each metropolitan area in the model and the salinity functions in Part A.

The third part (Part C) of this spreadsheet takes the information from the other sections of the spreadsheet and calculates the total annual cost per household item for each of the areas considered by the model. From the input spreadsheet on population and number of households, the number of households per area is multiplied by the average cost per household item and then divided by the average life of the item or percentage of household use for that item at a given salinity level. The costs are summed for each metropolitan area and are linked to the summary damage spreadsheet.

Commercial Damage Spreadsheet

This spreadsheet has been changed from the original Milliken-Chapman study model when commercial damages were calculated as percentage of household damages and added to total household damage estimate. MWD and their contractor Bookman and

Edmonson did some research based on the relationship between salinity and water use for commercial and institutional activities in their service area. MWD was able to collect commercial water use for particular use such as sanitary, cooling, irrigation, kitchen, and other uses. Based on the type of commercial water use, salinity cost functions were developed. From MWD water resource management plans, projected commercial water use was used to calculate salinity damages in future years. From their research on household and commercial salinity costs, it was estimated that the percentage of commercial salinity related damages to household damages is approximately 26 percent. For the Phoenix area, a similar methodology was used to estimate commercial salinity damages. The advantage of the commercial water use methodology is that it ties salinity damages to actual commercial water use for a given area. Due to the lack of available data for types of commercial water use in the other metropolitan areas, the 26 percent of household damages is used as an estimate for commercial damages in those areas. Ongoing research is attempting to better estimate the commercial related salinity damages for the Las Vegas/Clark County area.

Industrial Damage Spreadsheet

From research done for the MWD Salinity Management Study, salinity damages can be calculated for industrial water use. Salinity damage functions were developed based on three major types of industrial water use: process water, boiler feed water, and cooling water. MWD was able to estimate the amount of water used for these industrial types of production. Related salinity costs are on a dollar per acre-foot per mg/L basis. A change in salinity from the 500 TDS baseline would show a change in salinity costs as it relates to industrial water use. This methodology was applied to the Phoenix and Tucson metropolitan areas to estimate industry salinity costs.

Utility Damage Spreadsheet

The MWD research estimated the per capita costs for capital investments in replacement of water production and distribution facilities. The salinity useful life functions that were developed for the Milliken-Chapman study model are used in this spreadsheet. The methodology is similar to the Household damage spreadsheet. The per capita costs for water production and distribution costs are divided by the average life of the facilities based on the given salinity level and then multiplied by the metropolitan population for time period.

Agricultural Damage Spreadsheet

This spreadsheet estimates the change in gross revenue due to a change in crop yields of salt sensitive crops that receive Colorado River water in the Lower Basin. The agricultural areas considered by the model are irrigated lands in Central Arizona Project; La Paz County, Arizona; Yuma County, Arizona; Imperial County, California; Riverside County (non MWD), California; and MWD service area irrigated lands. This spreadsheet consists of three parts in calculating the salinity costs associated to crop yields.

The first part consists of the salinity-crop yield functions that were derived from a 1998 Reclamation study, *Final Report, Crop Salinity Estimation Procedures*, For the MWD, ten salinity-crop yield functions were used to estimate changes in crop yield due to changing salinity conditions of irrigation water in the service area. For the remaining irrigated areas in the Lower Basin, fourteen salinity-crop yield functions were selected due to their lower tolerances to salinity.

The next part of the spreadsheet consists of the irrigated crop acreages and crop prices. These were updated to year 2007 prices and acreages for the Central Arizona areas and Imperial County and Riverside County outside of the MWD service area.

The final part takes the above data and estimates the gross crop revenue based on the crop yield per acre at a given salinity level and the price per unit per acre times the total irrigated acres for that crop. This method is done to estimate the gross crop revenue at the 500 TDS baseline salinity level and the given salinity level to estimate the salinity damages.

Research data from the Central Arizona Salinity Study (CASS) was collected for CAP irrigated acres in the Phoenix area to identify for management costs associated with flushing out salts that build up in the soil. This would reduce the impacts on yield but would add to the costs of salinity due to the additional purchase of water. It is hoped that more research can be conducted to identify these types of costs in other agricultural areas in the Lower Basin.

Policy Related Spreadsheet

This spreadsheet is based on research conducted by MWD for their *Salinity Management Study* (June, 1999). One of the purposes of the MWD study was to conduct extensive research on the costs associated to meet groundwater and recycling requirements within their service area. The model calculates the costs of removing salts to maintain water quality requirements for groundwater and recycled water that is used extensively in service area. MWD were able to estimate the amount of water that drains into the groundwater system and the amount that is used for recycled water purposes. To meet regional water quality standards for these types of water sources, MWD was able to develop salinity cost functions (costs to desalt these sources of water) that could estimate the costs at given salinity level. As of now, this methodology has not been extended to other metropolitan areas in the model.

CONCLUSIONS

The Colorado River Salinity Damage Economic Model assesses the current and future economic damages in the Lower Colorado River Basin based on salinity levels at the Hoover, Parker and Imperial Dams. The model also is used to estimate the potential benefits of implementing salinity control projects in the Upper Colorado Basin by estimating the reduction in salinity related costs that would be incurred in the Lower Colorado Basin. The model can aid decision makers in project planning and implementation to meet the salinity criteria in the Colorado River Lower Basin.

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CONVERTED WETLANDS: UNINTENDED CONSEQUENCES

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ABSTRACT

"Not all wetlands fit the 'cattails and standing water' image many people have of what a wetland looks like. In reality, Oregon's wetlands are as varied as its landscape. They range from tidal salt marshes and red alder/slough cabbage swamps along the coast to season prairie wetland in the interior valleys; from Oregon ash/slough sedge swales in old river channels to willow-choked ravines; and from lake margins thick with bulrushes to mossy mountain fens. Because wetlands are so varied, wetland identification is sometimes tricky. Seasonal wetlands – the most common – are very dry by mid-summer. Also, many wetlands have been altered by activities such as farming and no longer "look like" wetlands."[3]

Because the jurisdictional reach of wetland protection legislation is broad, many agricultural users can be caught off guard when the Environmental Protection Agency (EPA) or Corps of Engineers (COE) makes a determination that agricultural land – including irrigated land – constitutes a wetland. Upon a determination by the EPA or COE of wetland delineation, the agricultural user is faced with several unintended consequences: (1) challenge the determination of wetland; (2) face enforcement and civil penalties; or (3) mitigate previous or future impacts on wetlands with the creation, enhancement or restoration of wetlands.

This paper focuses on the unintended consequences of the presence of converted wetlands on agricultural irrigated land. This paper examines (1) how a wetland determination may arise, (2) the federal and state agencies and regulations involved, (3) the options and considerations the agricultural user must face upon a wetland determination and, finally, (4) collaborative wetland mitigation.

INTRODUCTION

For most people the distinction between a wetland and a field of grass seems obvious, however, the reality of what constitutes a wetland is very complex and can often lead to unexpected results. For agricultural property owners, the complexity of what is, and what is not, a wetland can be a cause of great consternation. Both federal and state agencies have authority to determine whether a certain piece of land is in fact a wetland. A determination that the property in question is in fact a wetland will result in many

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[3] Oregon Department of State Lands, Wetlands Program, *Just the Facts*, (Nov. 2004), http://www.oregon.gov/DSL/WETLAND/docs/fact3_2004.pdf?ga=t.

unintended consequences for any unknowing agricultural property owner who has already made alterations to their land or wants to do so in the future.

In most cases, a property owner will have to interact with what can often be a daunting number of federal and state agencies to get a permit to fill any land delineated as a wetland and will also have to pay to replace it. If a property owner has already filled in what turns out to be a wetland, the consequences can include severe civil penalties, mitigation costs, and potentially criminal penalties, including imprisonment. Once a wetland determination has been made, a property owner does not have many choices other than to comply or attempt a costly legal challenge of the determination.

What is a Wetland?

The term "wetlands" is not defined in the Clean Water Act (CWA) but it has been defined in regulations by both the COE and the EPA.[4] A wetland is defined by the EPA and the COE to be "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions," and "generally include swamps, marshes, bogs, and similar areas."[5] State agencies may offer additional definitions. Oregon's definition mirrors the definition of wetlands given by the COE and EPA with small differences. Oregon removal-fill law, enforced by the Oregon Department of State Lands (DSL), defines a wetland to be "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions".[6]

Although definitions vary, it is clear that Removal-Fill Law definitions of "wetlands" can be broadly construed to include many types of land that would not usually be recognized as a typical wetland with cattails, standing water and other features found in a typical wetland. In addition, Oregon's jurisdiction includes all waters in the state, navigable and non-navigable. Oregon's jurisdictional reach over wetlands is not limited like federal jurisdiction so its definition covers a much greater geographical area.[7]

Unexpected Wetland Determinations

Which of the following would be considered a wetland by EPA?

1. Rangeland that has been ranched for 75 years and that is naturally saturated for 6 weeks each year under normal conditions?
2. The saturate banks of a man made irrigation ditch?
3. An agricultural pond constructed for winter storage and stock water?

[4] See 33 C.F.R. § 328.3(b) & 40 C.F.R. § 230.3(t) (2011).
[5] *Id.*
[6] Or. Rev. Stat. § 196.800(16) (2009).
[7] Or. Rev. Stat. § 196.800(14) (2009).

4. An irrigation ditch extending into a natural water way that is engulfed by the natural water way each winter but requires regular maintenance each spring?

Answer: All four, most likely.

THE PLAYERS AND RULES

There are many governmental agencies that are involved in regulating wetlands and often the rules are very complex. Because of the multiple federal and state agencies with jurisdiction over wetlands it is possible to be in compliance with the rules and regulations of one federal or state agency and still be in violation according to another. It can often be difficult to discern whether the wetland in question is regulated by both federal and state agencies or by just the state or just the federal government agencies. The complex way these agencies interact and their many, often inconsistent, rules and definitions can create many, and often costly, difficulties for an agricultural property owner. Accordingly, it is important to familiarize yourself with the players and their rules.

EPA and the Corp of Engineers

The principal federal agencies with jurisdictional power over wetlands include the EPA and the COE. Each federal agency is charged with enforcing section 404 of the CWA.[8] Section 404 prohibits discharging dredge or fill into a water of the United States, including wetlands, without a permit.[9] Filling or dredging wetlands that fall under federal jurisdiction may result in administrative, civil and/or criminal charges and similar repercussions under state removal/fill laws.

Section 404 of the CWA. The COE is the federal agency in charge of the day-to-day aspects of issuing permits under Section 404 of the CWA.[10] The EPA holds ultimate authority over the permitting process because it can veto or restrict any permitting decision by the COE if it determines that the discharge in question would unacceptably harm “municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas.”[11] “Fill” and “dredged material” are defined in the COE’s administrative rules.[12] “Filling” is placing materials into waters of the United States where the action causes a change in the bottom elevation or causes the water to turn into dry land.[13] “Dredged material” is defined as “material that is excavated or dredged from waters of the United States.”[14] In both cases, a property owner must have a permit to discharge “fill” or “dredged materials” into the waters of the United States including wetlands.[15]

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[8] 33 U.S.C. § 1344 (2006).
[9] 33 U.S.C. § 1344(f)(2) (2006).
[10] 33 U.S.C. § 1344(a) (2006).
[11] 33 U.S.C. § 1344(c) (2006).
[12] 33 C.F.R. § 323.2 (2011).
[13] *Id.*
[14] *Id.*
[15] 33 U.S.C. § 1344(f)(2) (2006).

Jurisdictional Reach of Section 404. The power of the federal government to regulate water comes from the United States Constitution which allows Congress to regulate commerce with foreign nations, with Indian tribes, and between the states.[16] When a body of water currently has one of these types of commerce taking place on it, ever had such commerce taking place on it in the past, or is capable of having such commerce take place it is considered to be "navigable."[17] The CWA defines "navigable waters" to mean the "waters of the United States, including the territorial seas."[18] "Waters of the United States," which is defined by administrative rule, includes "all other waters…[where their] use, degradation, or destruction…could affect interstate or foreign commerce" and specifically includes wetlands adjacent to such waters.[19]

The Supreme Court has recently interpreted the Commerce Clause to grant Congress the power to regulate wetlands that, "either alone or in combination with similarly situated lands in the region, significantly affect the chemical, physical, and biological integrity of other covered waters more readily understood as 'navigable.'"[20] In other words, if altering the wetland in question could affect a larger downstream waterway that has a hydrological connection to the wetland then the wetland likely falls under the jurisdiction of section 404. In April of 2011, the EPA published proposed guidance for field agents that adopted a very expansive view of the jurisdictional reach of the CWA.[21] The guidance document, if formally adopted, instructs field agents to find a hydrological connection even when there is a subsurface flow more than 12 inches below the surface.[22] Like the definition of "wetlands," the jurisdictional standard for section 404 does not provide a very definitive answer as to whether the wetland in question will be regulated or not. In most cases, unless the wetland in question is extremely isolated, it is likely a safe bet to assume that it is in fact a wetland that falls under section 404 jurisdiction.

Permit Requirements. Michigan and New Jersey are the only states in the United States that are Section 404 authorized.[23] A state that is Section 404 authorized takes over enforcement of Section 404 from the EPA and the COE. This means that land owners in every state that is not Section 404 authorized and that has a removal/fill law must get a permit from both the COE and the corresponding state agency. It is critical to determine which agency in your state administers removal/fill permits. Oregon DSL has a combined application form it shares with the COE that saves an applicant time but still results in a separate permit from the DSL and the COE.[24] When issuing a permit to fill or

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[16] U.S Const. art. I, § 8, cl. 3.
[17] 33 C.F.R. § 329.4 (2011).
[18] 33 U.S.C. § 1362(7) (2006).
[19] 33 C.F.R. § 328.3 (2011).
[20] *Rapanos v. United States*, 126 S.Ct. 2208, 2248 (2006).
[21] Environmental Protection Agency, *Draft Guidance on Identifying Waters Protected by the Clean Water Act* (April 2011), http://water.epa.gov/lawsregs/guidance/wetlands/upload/wous_guidance_4-2011.pdf (Accessed May 20, 2011).
[22] *Id.* at 17.
[23] Environmental Protection Agency, *State or Tribal Assumption of the Section 404 Permit Program*, http://www.epa.gov/owow/wetlands/facts/fact23.html.
[24] Oregon Department of State Lands, *Oregon Removal-Fill Program: Federal permit also required*, http://www.oregonstatelands.us/DSL/PERMITS/r-fintro.shtml.

discharge dredged materials into a wetland, the COE follows guidelines created by the EPA that are outlined in section 404(b)(1) of the CWA.

The guidelines for obtaining a Section 404 permit have been expanded and clarified by the EPA through administrative rules that can be found in 40 C.F.R. §§ 230.1-230.98. In order to receive a permit to discharge fill or dredged materials into a jurisdictional wetland, the COE must find that there is no practicable alternative to the proposed discharge site that would have a less adverse impact on the aquatic ecosystem.[25] An alternative site is practicable "if it is available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes."[26] Practicable alternative sites for the discharge of fill or dredged materials do not have to be in possession of the person seeking the permit in question.[27] The COE also assumes that that practicable alternative site exists if the purpose of the project is not "water dependent," i.e. the project does not have to be located on a wetland to achieve its purpose, "unless clearly demonstrated otherwise."[28] Any site that does not involve discharge of fill or dredged materials into a wetland is presumed to have less of an adverse impact on the aquatic ecosystem.[29] Also, no discharge of fill or dredged material is permitted if it would jeopardize the continued existence of a threatened or endangered species listed under the Endangered Species Act of 1973.[30] Highlighting the encompassing nature of review, section 404(b)(1) guidelines point out that when disruptions in the way water flows and circulates through the land occur, "apparently minor loss of wetland acreage may result in major losses through secondary impacts."[31] Each of the presumptions required by the COE as to the existence of a practicable alternative site, especially when the permit applicant does not have to own the land in question, can be difficult and costly for a property owner to "clearly demonstrate otherwise" and may lead to permit denial at the proposed site.

After applying the 404(b)(1) guidelines concerning restrictions on discharges and the existence of practicable alternative sites, the COE conducts its own public interest review before granting a section 404 permit.[32] The public interest review attempts to determine whether the cumulative effects of the proposed section 404 permit are beneficial or detrimental for the public at large. The COE has an extensive list of factors to weigh but some of those relevant to a agricultural property owner include consideration of: conservation, aesthetics, wetlands, flood hazards, fish and wildlife values, water supply and conservation, food and fiber production, "considerations of property ownership and, in general, the needs and welfare of the people."[33] The importance of each of these factors varies according to the nature of the particular action requiring a section 404

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[25] 40 C.F.R. § 230.10(a) (2011).
[26] 40 C.F.R. § 230.10(a)(2) (2011).
[27] 40 C.F.R. § 230.10(a)(3) (2011).
[28] 40 C.F.R. § 230.10(a)(3) (2011).
[29] *Id.*
[30] 40 C.F.R. § 230.10(b)(3) (2011).
[31] 40 C.F.R. § 230.41(b) (2011).
[32] 33 C.F.R. § 320.4 (2011).
[33] 33 C.F.R. § 320.4(a) (2011).

permit but the evaluation must always consider the "relative extent of the public and private need for the proposed structure or work."[34]

Lastly, the COE's public interest review lays out a special section concerning the effects on wetlands. The COE presumes that "most wetlands constitute a production and valuable public resource, the unnecessary alteration or destruction of which should be discouraged as contrary to the public interest."[35] The COE's rules list many functions considered important to the public interest from biological functions, water quality concerns, and flood concerns to their unique nature in the region or local area.[36] Courts give great deference to each of the administrative determinations made by the COE. This makes it extremely difficult for a property owner to challenge and overcome any COE conclusions made concerning whether a practicable alternative for the applicant's proposed action exists and whether the action is, or is not, in the public's greater interest.

USDA's "Swampbuster" Program

In addition to being aware of the definitions and regulations concerning wetlands under the CWA, an agricultural property owner must also be aware of the United States Department of Agriculture's "Swampbuster" Program. The jurisdictional reach of the Swampbuster Program is much broader than section 404 of the CWA and the definitions concerning wetland regulations and the consequences for violating those regulations differ. Under USDA's Swampbuster Program, an agricultural property owner who converts a wetland into cropland by "draining, dredging, filling, or any other means" in order to produce crops becomes permanently ineligible for crop insurance, disaster payments, price supports, and a variety of other benefits offered by the USDA related to any agricultural commodity produced on the filled wetland.[37] Because USDA is withholding benefits, rather than imposing penalties, the jurisdictional reach of the Swampbuster Program comes from the Spending Clause of the Constitution and is therefore not limited to wetlands considered to impact navigable waters.[38] This means that the Swampbuster program regulates all wetlands regardless of how isolated they are from other waters. Additionally, the Swampbuster program has different exemptions for certain activities than §404 of the CWA does and also only applies to converted wetlands after December 23, 1985.[39] Agricultural property owners who rely on USDA agricultural benefits must be aware of the differences between the Swampbuster Program, Section 404 of the CWA, and any applicable state removal/fill law as any action on what may be a wetland could involve a violation of all three laws.

[34] 33 C.F.R. § 320.4(a)(2) & (3) (2011).
[35] 33 C.F.R. § 320.4(b)(1) (2011).
[36] 33 C.F.R. § 320.4(b)(2) (2011).
[37] 16 U.S.C. § 3821 (2006).
[38] NEED CITE
[39] 16 U.S.C. § 3822 (2006).

State Agency Charged with Removal/Fill Law

As pointed out above, only Michigan and New Jersey are authorized by the EPA to administer permitting under section 404 of the CWA in place of the COE.[40] This means that the 48 other states have the choice to regulate wetlands as much or as little as they see fit. Also, the remaining 48 states are not restricted to regulating wetlands that only have the potential to cause impact navigable waters of the United States. For example, Oregon's jurisdictional reach over wetlands, as set out by statute, includes "waters of the state" whether they are navigable or non-navigable.[41] In other words, a state can regulate remote and completely isolated wetlands to whatever extent the state desires.

In addition to potentially having a different jurisdictional reach than federal agencies, states often have different definitions concerning wetland regulation. In Oregon, "fill," as compared to the EPA's definition above, means a "total of deposits by artificial means equal to or exceeding 50 cubic yards or more of material" into any waters of the state."[42] At the same time, "fill" also means any amount of material deposited into waters of the state if in an Essential Salmon Habitat (ESH) or a designated Scenic Waterway.[43] So while a property owner outside of an ESH or Scenic Waterway may not need a permit under Oregon's definition of "fill," the same property owner may need a permit from the COE even when moving less than 50 cubic yards of material within a wetland area. On the other hand, a property owner may be outside of the jurisdiction of the COE or not moving enough "fill" to fall under the EPA and COE's definition of "fill," and still need a permit under Oregon's definition of "fill" if they are inside an ESH or Scenic Waterway. Due to the fact that each state potentially has different definitions and regulations concerning wetlands, agricultural property owners must be aware of both federal and any applicable state regulations, especially making sure to note any difference between the two, in order to know whether a permit is, or is not, required for earth altering activities on their property.

On top of the regulations each state has, section 401 of the CWA presents one additional hurdle to any property owning seeking to make alterations to their property that would require discharging fill or dredged material into a wetlands. Section 401 applies to all programs where the applicant needs a federal license or permit, including section 404 permits, and requires the applicant to get certification from the state that the proposed project will not violate non-404 related sections of the CWA administered by the state.[44] This includes water quality standards created by that state that are often not quantified but are descriptive in nature. This gives a state a great deal of leeway in determining whether the water quality standards could be violated by the proposed action. In Oregon, even though DSL is the agency that processes Oregon's removal/fill permit, it is the Oregon Department of Environmental Quality that administers section 401 certification under the

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[40] Environmental Protection Agency, *State or Tribal Assumption of the Section 404 Permit Program*, http://www.epa.gov/owow/wetlands/facts/fact23.html.
[41] Or. Rev. Stat. § 196.800(14) (2009).
[42] Or. Admin R. 141-085-0510(35) (2011).
[43] *Id.*
[44] 33 U.S.C. § 1344(a) (2006).

CWA.[45] In effect, section 401 gives the states the last say by giving it veto power over any decision made by the EPA and the COE concerning section 404 permits even if the state's own wetland regulations are inapplicable or nonexistent.

HOW A WETLAND DETERMINATION MAY ARISE

A wetland determination can occur either cooperatively at the instigation of a property owner prior to making some type of alterations to their property or after an alteration has already been made and a state or federal agency comes to investigate. The COE has produced multiple wetland delineation manuals for determining if an area is a wetland that are tailored towards the various climates found within the United States.[46] Oregon DSL, for example, maintains a website that includes the various wetland delineation manuals applicable to Oregon created by the COE and includes a link to maps of wetlands called the Statewide Wetlands Inventory.[47] These delineation manuals and maps may help an agricultural property owner to initially determine whether or not a wetland exists on their property. However, the final determination is always made by the relevant state or federal agency and can occur at various points in a construction or modification project if the property owner does not first consult with the correct agencies.

When beginning a new construction project a prudent property owner will consult with the state and federal agencies charged with enforcing removal/fill laws to determine if any wetlands will be impacted. A property owner's lack of knowledge concerning the jurisdictional reach of removal/fill laws and what exactly constitutes a wetland can often lead to expensive and time consuming repercussions from starting a new construction project or from modifying an existing project that is already supported by a removal/fill permit. When a property owner consults the relevant state and federal agencies before beginning a new construction property or modifying an existing project that would result in a violation of removal/fill laws the chances of violating the removal/fill law are significantly lessened and the consequences related thereto are less severe.

CONSIDERATIONS OF THE PROPERTY OWNER

When a property owner is faced with a positive wetland determination there are not many viable options available to overcome the relevant agency's decision. The first thing a property owner should do is to check whether or not any exception under any of the applicable removal/fill laws applies to the activity in question. Next, which is often costly and many times futile, is to challenge the science used to make the wetland determination or to challenge the whether the agency has jurisdiction over the wetland in question. A third, and very difficult, choice is to argue that a regulatory taking has occurred under the United States Constitution. If none of these arguments prevail, a

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[45] Oregon Department of Environmental Quality, *Water Quality: Section 401 Certification*, http://www.deq.state.or.us/wq/sec401cert/removalfill.htm (Accessed May 23, 2011).
[46] U.S. Army Corps of Engineers, *Hydrogeomorphic Approach for Assessing Wetlands Functions: Guidebooks*, http://www.el.erdc.usace.army.mil/wetlands/guidebooks.html (Dec. 2010).
[47] Oregon Department of State Lands, *Wetlands/Waterways Removal-Fill: Are there Wetlands On my Property?*, http://www.oregon.gov/DSL/PERMITS/wetlanddelineation.shtml (Accessed April 14, 2011).

property owner who does not agree with the wetland determination could choose to go ahead with the construction project without a permit and then face extensive fines and/or criminal penalties. Lastly, a dissatisfied property owner can attempt to work collaboratively with the relevant state and federal agencies in developing permit conditions and a mitigation plan acceptable to all parties.

Applicable Exception?

Each of the removal/fill laws, both state and federal, have certain activities that are exempt even though they result in what would technically be a violation of the laws and disturbance of a wetland. Section 404 of the CWA provides an extensive list of activities that are exempt from the prohibition of discharging dredge or fill material into wetlands and other waters of the United States.[48] The exemptions, for example, include many normal ranching and farming activities like plowing, seeding, maintenance of farm or stock ponds, maintenance of irrigation or drainage ditches, and others but such activities are only exempt if they are not subject to section 404(f)(2).[49] Section 404(f)(2) limits the applicability of the exemptions by stating that any activity "having as its purpose bringing an area of the navigable waters into a use to which it was not previously subject…shall be required to have a permit under this section."[50] This clause means that an activity that causes a discharge of dredged or fill material into a wetland is exempt if the purpose of the activity is to continue the use that particular piece of property has already been used for – like farming for example – rather than filling in a wetland that has never been used for any particular purpose. For the agricultural property owner, the exemptions under section 404 are really only available for activities on land that is potentially a wetland when that land has already been farmed or put to some other agriculturally related used. Once again, property owners must be familiar with any applicable state exemption list because they may deviate from federal exemptions.

In addition to certain exempt activities, section 404 of the CWA, like the Swampbuster Act, exempts the discharge of dredged or filled material on "prior converted croplands" because such lands are specifically excluded from "waters of the United States."[51] "Prior converted wetlands," which are a type of "prior converted croplands," are defined to be any "wetland that has been drained, dredged, filled, leveled or otherwise manipulated (including any activity that results in impairing or reducing flow, circulation, or reach of water) prior to December 23, 1985, for the purpose [of agricultural production]."[52] This exemption essentially works hand in hand with the activities exemption just discussed because any activity that would not be exempted after December 23, 1985, would have required a permit to have originally filled the wetland at issue. Again, if states have a similar exemption agricultural property owners must be aware that it may be different than the EPA's and COE's. For example, Oregon exempts from regulation any wetland that was converted prior to June 30, 1989, rather than December 23, 1985. Oregon, in

[48] 33 U.S.C. § 1344(f)(1)(A)-(F).
[49] 33 U.S.C. § 1344(f)(1) & (2) (2006).
[50] 33 U.S.C. § 1344(f)(2).
[51] 40 C.F.R. § 230.3(s)(7) (2011) –definitions for the EPA/COE 404(b)(1) Guidelines.
[52] 7 C.F.R. § 623.2(f) (2011).

addition to having exemptions for activities that are similar to the EPA's and COE's, has another set of different exempt activities applicable to Exclusive Farm Use land.[53]

Challenge Wetland Jurisdiction or Permit Determination

If there is no applicable exemption available, a property owner can argue that the property in question does not fall under state or federal jurisdiction or that the COE erred in denying a section 404 permit. As previously discussed, the COE has jurisdiction over all wetlands that effect downstream navigable waterways. The COE uses criteria set out by rule when making a jurisdictional determination concerning regulation of a wetland and a property owner may challenge the application of these criteria only after having received the COE's final decision.[54]

The jurisdictional determination or permit denial may be appealed by the submission of a Request for Appeal (RFA) by the property owner.[55] The RFA must be submitted to the COE's division engineer within 60 days of having received the COE's jurisdictional or permit decision.[56] The RFA must state the specific reason(s) for the appeal and the reason must be more than disapproval of the COE's positive determination of jurisdiction or the denial of a permit.[57] A basis for appeal may include procedural errors, incorrect application of the law or regulations, incorrect application of wetland delineation criteria, an incorrect application of Section 404(b)(1) Guidelines, and others.[58] Challenging the application of the factors the COE uses in jurisdictional and permit determinations is an often lengthy and costly process due to the fact intensive and scientific nature of the COE's case-by-case determinations. Also, Property owners who have applied for and were granted a Section 404 permit need to be aware that the right to appeal the COE's determinations and permit conditions are lost if the property owner signs the permit.[59]

Takings

Another route for a property owner who is denied a Section 404 permit when there is no exemption and the COE does in fact have jurisdiction over the wetland in question is to make a regulatory takings claim under the United States Constitution. A regulatory taking can occur when a Section 404 permit, or the relevant state permit, is denied to preserve the public wetland uses, such as increased water quality or habitat for endangered species. A regulatory takings claim may only be made after the relevant agency has made a final decision concerning the permit.[60]

It is extremely difficult to prevail on a takings claim involving wetlands. To prevail on a taking claim, a property owner must demonstrate that the denial of a permit has deprived

[53] Or. Admin. R. 141-085-0530 & 141-085-0535 (2011), Or. Rev. Stat. § 215.203 (2009).
[54] 33 C.F.R. §§ 331.1-331.12 (2011)
[55] 33 C.F.R. § 331.5(a)(1) (2011).
[56] 33 C.F.R. § 331.5(b)(6) (2011).
[57] 33 C.F.R. § 331.5(a)(2) (2011).
[58] *Id.*
[59] 33 C.F.R. § 331.5(b)(1) (2011).
[60] *Hodel v. Virginia Surface Mining & Reclamation* 452 U.S. 264, 293-297 (1981).

the property owner's land of all economically beneficial uses.[61] In other words, a property owner must make the extremely difficult showing that there are absolutely no other viable economic activities that could take place on the land in question in order to win a regulatory takings claim.

Enforcement and Penalties

A property owner who discharges fill or dredged material into a wetland without a permit or in a manner that violates a permit may face administrative, civil, and potentially even criminal penalties under both state and federal law. The EPA and COE may enforce Section 404 either administratively or judicially. The mega difference between the two choices is that administrative penalties have a maximum fine amount whereas civil penalties do not.[62] Another difference is that guilt is determined by an administrative law judge in the administrative context and by a jury in the civil context.[63] The civil penalty was originally set at a maximum of $25,000 per day in violation of the CWA but this has been increased to a maximum of $37,500 per day.[64]

A person's intent to fill a wetland is irrelevant for the purposes of administrative and civil judicial penalties but it is very important for criminal enforcement of Section 404. If a person unknowingly filled in a wetland sanctions include per day fines and up to one year imprisonment whereas any person who knowingly fills in a wetland faces stiffer per day penalties and up to three years in prison.[65] Ultimately, it is very unwise for a property owner to discharge fill or dredged materials in an area that may be a wetland without a wetland determination by the COE and, if required, a Section 404 permit because the ramifications, in both fines and prison time, can be extensive.

Collaborative Approach

The final approach for a property owner who requires a removal/fill permit or who has already inadvertently violated a removal/fill law is to work collaboratively with the relevant agencies. Applying for a permit after a positive wetland determination has been made and before any actual construction on the property in question has begun is almost always the least costly alternative for a landowner. If construction has already begun when a wetland determination is made, a property owner who wishes to work collaboratively with the COE can also apply for an after-the-fact permit. Lastly, a property owner who has already begun construction on a wetland without a permit may enter into a consent order and mitigation plan with the COE.

<u>Applying for a Permit</u>. As previously discussed, the COE and relevant state agency have their own internal factors they must consider when deciding whether or not to grant a

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[61] See generally - *Penn Central Transp. Co. v. New York City*, 438 U.S. 104 (1978), *Lucas v. South Carolina Coastal Council*, 505 U.S. 1003 (1992).
[62] 33 U.S.C. § 1319(d) & (g) (2006).
[63] *Tull v. United States*, 481 U.S. 412 (1987).
[64] 33 U.S.C. § 1319 (2006).
[65] *Id.*

removal/fill permit. In order for the COE and state agency to make these determinations a property owner has to provide a significant amount of information regarding the purpose of the project, the project's scope and potential impact on the surrounding water systems. The Oregon Department of State Lands (Oregon DSL) permitting process, which allows a joint application for a permit from the COE and DSL, provides a good example of some of the detail that is required when applying for a removal/fill permit.[66]

A sample of the information required by Oregon DSL includes a completed application form with any necessary maps, photos, or drawings.[67] The project site location information is also required which includes the "township, range, quarter/quarter section and tax lot(s), latitude and longitude, street location if any, and location maps with site and location indicated."[68] Project information must also include a description of all removal/fill activities, volumes of fill and removal expressed in cubic yards, and the area of impacted area expressed to the nearest hundredth or thousandth acre depending on the project size.[69] The application must have a description of the need for the project that is "specific enough to allow the Department to determine whether the applicant has considered a reasonable range of alternatives."[70] The applicant must also provide a slew of other types of information ranging from the potential changes to the hydrologic characters of the waters of the state, the presence or threatened or endangered species, to an analysis of the practical alternatives the property owner considered and why the proposed activity will have the least adverse impact as compared to the alternatives.[71] Lastly, the Oregon DSL has the discretion to hold a public hearing to allow interested parties to voice their concerns about the proposed project.[72] As can be seen from this sample of what is required by Oregon DSL, the amount of information needed to apply for a permit is quite extensive and can be both time consuming and expensive to prepare.

<u>After-the-fact-permit</u>. The COE has the discretion to grant after-the-fact Section 404 permits to authorize any illegal filling activities and does so using its normal permit application procedures. Even if the COE would have granted the permit prior the activity that discharged dredged or fill material, it will not do so unless certain corrective measures are taken and other factors are accounted for.[73] Initial corrective measures are determined by the COE's district engineer and will include halting the project while consideration of the permit goes forward.[74] In addition to any of the other corrective measures the district engineer determines to be necessary, which will include mitigation, an after-the-fact permit will not be granted if a previous federal or state permit for the activity has already been denied or there is any ongoing enforcement litigation occurring

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[66] Oregon DSL Joint Application form may be found at http://oregonstatelands.us/DSL/PERMITS/docs/joint_permit_app_07-09.pdf.
[67] Or. Admin. R. 141-085-0550(5) (2011).
[68] Or. Admin. R. 141-085-0550(5)(b) (2011).
[69] Or. Admin. R. 141-085-0550(5)(d) (2011).
[70] Or. Admin. R. 141-085-0550(5)(e) (2011).
[71] Or. Admin. R. 141-085-0550(5) (2011).
[72] Or. Admin. R. 141-085-0560 (2011).
[73] 33 C.F.R. § 326.3(e)(1) (2011).
[74] *Id.*

by other state or federal agencies.[75] If the permit is ultimately denied or the applicant refuses to take the stipulated corrective actions, the district engineer may recommend commencement of criminal or civil legal action to the COE or local U.S. Attorney.[76]
Consent order and mitigation. A property owner who has already begun an activity that resulted in an unpermitted filling of a wetland may also enter into a consent order and mitigation plan with COE and state agency. A consent order is essentially an agreement between a property owner and the agency concerning what fines will be paid for the illegal filling and any corrective measures, including a mitigation plan, that need to be taken. When both a state agency and the COE assert jurisdiction over the matter they may not always agree on whether an after-the-fact permit should be granted, what fines should be collected, or what the extent of mitigation should be. If the COE has jurisdiction it can effectively veto a state agency decision through imposing cost prohibitive fines and/or mitigation requirements while a state with its own removal/fill law can effectively do the same for any of the COE's decisions. As previously discussed, the CWA gives states broad discretion in signing off on any decision made by the COE and EPA regardless of whether the state has its own removal/fill laws that would apply.[77] Ultimately, entering into a consent order will most likely result in a more positive outcome for a property owner than facing administrative, civil, or criminal penalties that could result from not cooperating with the state agency and the COE.

MOVING FORWARD WITH MITIGATION

Once a property owner, whether before or after any filling activity has occurred, has made their way through the steps required by the applicable removal/fill laws, the last step is to prepare a mitigation plan. Before examining mitigation further, it is important to note that the fact that a property owner is willing and able to mitigate the proposed filling activity does not affect the practicable alternatives review conducted by the COE under the Section 404(b)(1) Guidelines. If the COE determines that a practicable alternative site exists, even if it is not owned by the applicant, and that will have no or less impact on wetlands the COE can deny the permit on that basis alone if it chooses to.[78] The COE and EPA entered into a Memorandum of Agreement (MOA) concerning how the mitigation requirements from the section 404(b)(1) Guidelines will be determined on February 6, 1990.[79] The MOA is intended to provide guidance to agency field personnel for determining the type and level of mitigation necessary to achieve the goals and objectives of section 404 of the CWA.[80]

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[75] *Id.*
[76] 33 C.F.R. § 326.(e)(2) (2011).
[77] 33 U.S.C. § 1344(a) (2006).
[78] 40 C.F.R. § 230.10(a) (2011).
[79] Environmental Protection Agency, *Memorandum of Agreement between the Environmental Protection Agency and the Department of the Army Concerning the Determination of Mitigation Under the Clean Water Act Section 404(b)(1) Guidelines* (Feb. 6, 1990), http://water.epa.gov/lawsregs/guidance/wetlands/mitigate.cfm.
[80] *Id.*

A Closer Look at Mitigation

According to the MOA, the purpose of wetland mitigation under section 404 is to help the COE and EPA to "implement the objective of the CWA to restore and maintain the chemical, physical and biological integrity of the Nation's waters, including wetlands."[81] The COE and EPA determined that the best way to accomplish this goal was to have a policy of zero net loss of wetlands.[82] Mitigation, as pointed out in the MOA, is defined by rule as "avoiding impacts, minimizing impacts, rectifying impacts, reducing impacts over time, and compensating for impacts."[83] The MOA simplifies this definition by formulating three general types combinable of mitigation: avoidance, minimization and compensatory mitigation.[84] To sum up the evaluation process, the COE will first seek to avoid the impact to the maximum extent practicable, then to minimize the remaining impacts, and, lastly, require compensation for any unavoidable wetland loss.

Avoiding the Impact

The MOA highlights that section 404(b)(1) Guidelines allow for discharges of fill or dredged material for only the least environmentally damaging practicable alternative.[85] The first way to avoid the impact is to locate the site of the project in an area where no impact on wetlands will occur and the COE will require this if a practicable alternative exists that does not other adverse environmental consequences.[86] At this point in the evaluation, the effect of any planned mitigation is irrelevant in determining whether or not there is a practicable alternative. The COE could also require reductions in the project's scope or, for example, installation of erosion control structures.[87]

Minimizing the Impact

After the COE has been convinced that there is no practicable alternative site for the proposed removal/fill activity, the COE will often require the applicant to take steps to minimize any impacts on wetlands. The COE and EPA both have lists describing several, but not all, of the potential steps and modifications an applicant may have to make to minimize the impact.[88] The COE, for example, says it may require changes in "scope and size; changes in construction methods, materials, or timing; and operation and maintenance practices or other similar modifications that reflect a sensitivity to environmental quality within the context of the work proposal."[89] The minimizing actions listed under the Section 404(b)(1) Guidelines are much more exhaustive and

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[81] *Id.*
[82] *Id.*
[83] *Id.*
[84] *Id.*
[85] *Id.*
[86] *Id.*
[87] 33 C.F.R. § 320.4(r) (2011).
[88] 33 C.F.R. § 320.4(r) (2011), 40 C.F.R. § 230.70-230.77 (2011).
[89] 33 C.F.R. § 320.(4)(r)(1)(i) (2011).

include changes concerning location, material to be discharged, methods of discharge, technology, and many other more specific actions.[90]

Preparing a Wetland Mitigation Plan

Once the COE and EPA are satisfied that as many minimizing actions as possible are included in the project and that the project is in the public interest, a property owner is required to take compensatory mitigation for unavoidable impacts.[91] The first step in mitigation is for the applicant to prepare a draft mitigation plan and submit it to the COE's district engineer and then submit a final draft after addressing any comments made by the district engineer.[92] The information required to be included in the mitigation plan is extensive and includes physical descriptions, why the site was chosen and how it will address the needs of the watershed, construction methods, a maintenance plan, a monitoring plan, and many other subjects.[93] A mitigation plan must be approved before any work on wetlands or any other jurisdictional waters can commence.[94]

Mitigation may be performed through restoration, enhancement, and creation of wetlands and may even include preservation of wetlands.[95] The preferred method of mitigation is restoration because of the higher potential for successful functional replacement of the impacted wetland and because restoration does not involve altering other ecologically important habitats.[96] Other methods of mitigating include mitigation banks, in-lieu fee program credits, and permittee-responsible mitigation monitored by the COE.[97] Regardless of the chosen method, mitigation can be extremely costly for property owners and in many cases can be cost-prohibitive for any proposed construction activities.

CONCLUSION

Under the Section 404 of the CWA and many analogous state laws, wetlands are not always what most people think of when they imagine a stereotypical wetland and this has led to many unintended consequences. Property owners who have already or wish to conduct activities that may result in altering a wetland in violation of removal/fill laws are faced with a confusing array of federal and state agencies. Once a positive wetland determination has been made, property owners who wish to avoid administrative, civil, and/or criminal penalties do not have many viable options other than cooperating with the involved agencies. Cooperating and negotiating with the relevant agencies is both complex and time consuming and can also be cost-prohibitive for many property owners. Even if an agreement is struck between at property owner and the agencies so that the project may go forward, mitigation is almost always required and can also be extremely time consuming and costly. Ultimately, many property owners who are unaware that

[90] 40 C.F.R. §§ 230.70-230.77 (2011).
[91] 40 C.F.R. § 230.91(c)(2) (2011).
[92] 40 C.F.R. § 230.94(c)(1) (2011).
[93] 40 C.F.R. §§ 230.94(c)(2)-(14) (2011).
[94] 40 C.F.R. § 230.94(c)(1) (2011).
[95] 40 C.F.R. § 230.91(a)(2) (2011).
[96] *Id.*
[97] 40 C.F.R. § 230.91(b) (2011).

parts of their property are in fact wetlands get swept up in this process and may spend years dealing with the repercussions of digging a simple ditch in what appeared to them to be a field of grass.

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PUEBLO DE COCHITI: A CASE STUDY ON THE STRUGGLE FOR IRRIGATION EFFICIENCY

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ABSTRACT

Like all Rio Grande Indian pueblos, irrigated agriculture is central to Pueblo de Cochiti culture, and has been since time immemorial. Pueblo de Cochiti irrigated agriculture suffered two major setbacks in the 1900's. Cochiti Pueblo was incorporated into the newly formed Middle Rio Grande Conservancy District in 1928. While intentions were good, insufficient maintenance, decreased diversions, and design flaws resulted in a slow decrease in irrigated acreage over the years. The construction of the U.S. Army Corps of Engineers' Cochiti Dam from 1973-1975 immediately upstream from Pueblo farmlands resulted in a rise in the groundwater table. A subsurface pipe drainage system was constructed in the 1990's to lower the water table in the farm fields. However, earthen irrigation ditches had eroded while underwater. An entire generation had lost the traditions, equipment, and expertise to practice irrigated agriculture.

After these setbacks, the Pueblo de Cochiti had to essentially start over with modernizing its system and training and encouraging tribal members to farm. New technology was available, such as pressure pipe systems, high flow turnouts, soil science information, and new seed varieties. A master plan was developed for bringing lands back under production with concrete lined ditches, pressure pipe systems, and high flow turnouts. This paper examines the internal and institutional changes and incorporation of modern irrigation practices which helped reinvigorate Pueblo de Cochiti agrarian culture and increase irrigation efficiency and profitability.

HISTORY

The Pueblo de Cochiti is located in the Middle Rio Grande Valley in New Mexico. The Pueblo Indians have historically been primarily farmers rather then hunter-gatherers. Before Spaniards first explored the area in 1539, the pueblo Indians were practicing irrigated agriculture. Some of the ancient canals noted by the Spaniards are still in use today.[2] Antonio de Espejo wrote that, in 1582, "They have fields of maize, beans, gourds, and piciete (tobacco) in large quantities which they cultivate.... Some of the fields are under irrigation, possessing very good diverting ditches, while others are dependent upon the weather."[3] Josiah Gregg, writing in 1844, "described the Pueblo Indians generally as the best horticulturists in New Mexico, furnishing most of the fruits and a large percentage of the vegetables for the market of that province."[4]

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[2] Burkholder, p. 23.

[3] Burkholder, p. 23.

[4] Clark, p. 8.

Today, the practice of irrigated agriculture is still central to Pueblo culture. The land base available for irrigation has not changed substantially in centuries.

Aerial photography of the Pueblo de Cochiti in 1934 (Figure 1) shows many small farm fields oriented in different directions. These fields, totaling about 350-400 acres on both sides of the Rio Grande, were irrigated by a system of canals, laterals, and farm ditches which diverted water from the Rio Grande. The system shown in Figure 1 would have been representatiave of historical farming at the Pueblo de Cochiti, as it predated the construction of more modern irrigation facilities.

A cooperative, joint endeavor was required to maintain these irrigation systems. The community was responsible for maintaining the acequias (irrigation ditches), using the waters, harvesting, and storing the produce. There was a centralized system of control for distributing land and maintaining the irrigation system. There is a practice dating to ancient times requiring male pueblo members to do their fair share in repairing and cleaning the ditches each spring. There was no private land ownership. Kinship groups were assigned land, which they could continue to farm as long as the tracts were kept in production. The tracts were small and irregularly shaped, and varied in size from one-half to two or three acres.[5]

Today at Cochiti Pueblo, the tribal council takes requests for land from individual males who want to farm and grants land assignments. Until recently, the land assigned to an individual farmer was limited to 10 acres. Although the 10-acre rule is no longer strictly observed and some individuals farm more than 10 acres, the tribal council attempts to limit the size of assignments so that there is farm land available for all tribal members who want to farm.

The small, irregularly shaped plots of land shown in Figure 1 were cultivated by different families to raise mostly corn, chile, beans, squash, other vegetables, and fruit for family consumption. All irrigation was from an extensive system of earthen ditches, and fields were not mechanically leveled. The occupation of most families at the time was farming, so there was sufficient manpower for the labor-intensive nature of raising garden crops in this manner. Some hay and other crops for livestock owned by the families would have also been grown.

The irrigated area consists of old flood plains of the Rio Grande. There is some natural terracing resulting from times when the Rio Grande flowed at higher elevations located on these terraces. The Rio Grande is a rift valley, with the valley dropping over time. The irrigated portion of the valley is less than a mile wide at this point. There are no levees to contain the Rio Grande through this reach. Significant flooding of this area took place prior to the construction of upstream flood control reservoirs. The last time there was significant flooding was in 1941 and 1942.

Settlement upstream in Colorado's San Luis Valley beginning in the mid-1850's led to a progressive increase in farming and use of water from the Rio Grande. Eventually, about

[5] Clark, p. 8

650,000 acres were being farmed in 1926, which is roughly the same acreage being farmed today.[6] Until enforcement of the Rio Grande Compact in the 1960's and 1970's, nearly all waters of the Rio Grande were exhausted in Colorado except for flood water, drainage return flow, or water which could not be utilized in Colorado.[7] More waters were added to the flow of the Rio Grande upstream of the middle valley in New Mexico. However, the decrease in flow, together with an increase in sediment supply resulting from livestock overgrazing in the watershed, led to an aggrading Rio Grande which could no longer transport its sediment load. As the river rose due to sediment deposition, it would become higher than surrounding farm lands. Although it may not have breached man-made or natural levees, the seepage from the Rio Grande to the surrounding farm lands waterlogged those lands, leading to a decrease in irrigated acreage. At the time the Spanish first settled the area, it was estimated that about 25,555 acres were under cultivation in the middle Rio Grande valley, solely by the Indians. By 1880 the irrigated acreage totaled about 124,800 for both Indians and non-Indians, but then it decreased to about 40,000 acres in 1925, with about 84,800 previously farmed areas now water logged or unable to receive a sufficient water supply.[8]

Figure 1. Pueblo de Cochiti farmlands, 1934.[9] North is at the top of the photo.

[6] Debler and Elder, p. 7.
[7] Burkholder, p. 26.
[8] Burkholder, p. 35.
[9] Courtesy of the Pueblo de Cochiti.

Figure 2 shows the same area in 1954. The same pattern of small, irregularly shaped farm fields can be seen. However, there is significant loss of lands to flood damages and waterlogging on both sides of the river. It can be seen that much of the farmland adjacent to the Rio Grande has been damaged by flooding and is no longer in production. In some areas, there are active river channels where there was once farmland.

Figure 3, taken in 1963, shows even more lands lost to production, presumably due to waterlogging. There had also been serious long-term drought conditions since the floods of 1941 and 1942 which may have also contributed to some lands being put out of production. Traces of drainage courses can be seen in the damaged land. Figure 3 also shows the beginnings of repairs undertaken by the Bureau of Indian Affairs to terrace, grid, and level farmlands which were still being farmed. These farm fields average about 550-600 ft in length, although some are nearly 900 ft long. The farm field width varies depending on the terrace width. Rectangular farm fields this size lend themselves more readily to the use of mechanized farm equipment and the growing of alfalfa and other cash crops rather than having many small vegetable gardens.

Figure 2. Pueblo de Cochiti farmlands, 1954.[9] North is at the top of the photo.

Figure 4, taken in 1975, shows that most of the terracing and gridding of farmlands is complete. There is a small area on the west side of the river (bottom left of the photo) that still appears flood damaged. There are some small plots left on the southerly west end of the farm fields (bottom left of photo). Also shown is the U.S. Army Corps of Engineers' Cochti Dam, which was just beginning to impound water. This facility was built as part of the Middle Rio Grande Project to provide flood control protection to downstream communities, especially Albuquerque. The pueblo did not want this facility built on their lands, but was forced to acquiesce. They lost valuable farm lands, which are now submerged beneath the reservoir or are under the dam itself. They also lost some cultural treasures where the reservoir outlet works is now located.

Figure 3. Pueblo de Cochiti farmlands, 1963.[9] North is at the top of the photo.

Figure 4. Pueblo de Cochiti farmlands, 1975.[9] North is at the top of the photo.

For Cochiti Pueblo, the irony of having a flood control structure on their land to protect other communities is that their own farmlands were flooded out by the rising groundwater table resulting from impoundment of water behind the dam. Once-fertile farm fields were turned into wetlands incapable of supporting agriculture. Some fields even became duck ponds. Earthen farm ditches eroded and were no longer usable. Cochiti Pueblo sued the Corps of Engineers, forcing the Corps to construct a subsurface perforated pipe drainage system to drain their farm fields. The settlement and construction of the drainage system did not take place until the early 1990's.

Prior to construction of Cochiti Dam, the Rio Grande carried more sediment than it could transport through the middle valley, resulting in sediment deposition and aggradation. After construction of Cochiti Dam, these sediments are dropped out in the reservoir, and the releases from Cochiti Dam have very little sediment. These released waters are erosive, carrying far less sediment than their capacity. Released waters increase their sediment load by picking up material from the bottom and sides of the river channel. These sediment-starved waters released from the reservoir have changed the character of the Rio Grande downstream of the dam. Instead of an aggrading, braided stream channel, the Rio Grande is now a narrow, incised channel with a tendency to meander and destabilize banks, threatening farmlands adjacent to the river. One fortunate result of the channel incising is that the river is low enough for the subsurface pipe drainage system in the farm fields to have an outfall, making the pipe drainange system feasible.

Waterlogging of lands from an aggrading river system and periodic flooding of the Rio Grande into adjacent farm lands was not unique to the Pueblo de Cochiti. This was occuring in all riverside communities, both Indian and non-Indian, from Cochiti Pueblo south over 150 miles to San Marcial. These problems led to the formation of the Middle Rio Grande Conservancy District in the 1920's. The District was to provide flood control, drainage, and modernized irrigation systems throughout the valley. At the time, there were about 70 individual ditch headings into the Rio Grande throughout the middle valley. There were no diverison dams. The District proposed combining these 70 ditch systems and constructing four diversion dams to serve the same area. The new diversions would be much more efficient, allowing water to be diverted into the irrigation system even during low flow conditions when the ditch headings would have been inoperative or highly inefficient. In order to combine the ditch systems and have only four diversion points, the District had to obtain easements through the Indian lands of six Middle Rio Grande pueblos: Cochiti, Santo Dominto, San Felipe, Santa Ana, Sandia, and Isleta. To acquire these easements required an act of Congress. The federal Act of March 13, 1928 provided for inclusion of these six pueblos into the District. The Act provided for the District to recongnize the senior prior and paramount water right for the Indian lands then irrigated, 8,847 acres. It also provided for junior Indian water rights to be recognized on 12,600 acres which would be able to be drained and receive water through the new District system. About half of the supply ditches to Indian lands, primarily main canals and laterals, would now be District facilities, while the other half of the ditches, including other laterals and farm ditches, would remain as Indian ditches.

It was fully expected that Indian lands would be improved and receive a better and more reliable water supply through the newly formed District. However, these good intentions were not always realized. Some of the problems resulted from insufficient operation and maintenance, decreased diversions, and design flaws. The District was nearly bankrupt several times, so there was not always funding necessary to provide adequate operation and maintenance. Some check structures were not operable, and some that were operable were never used. The District has been under pressure over the years from the New Mexico Office of the State Engineer and others to decrease diversions. Decreased diversions resulted in decreased elevation or head in their supply ditches, and without enough check structures in the system to maintain adequate head, many farm fields were slowly deprived of an adequate water supply over the years. Some design flaws in the delivery system meant that some fields could no longer receive an adequate water supply because the supply ditch water surface elevation was at an elevation roughly equal to or lower than the fields to be irrigated.

There were also design flaws in some of the Indian ditches which were supplied from District ditches. For example, concrete farm ditches to supply the east side fields at Cochiti Pueblo (Figures 1-4) all ran uphill and the ditch inverts were lower than the farm fields they were to irrigate. One 150-ft long concrete farm ditch started out from the main canal with a high water mark about six inches deep, and ran uphill so that the high water mark 150 ft downstream was only one inch deep. Even then, the high water mark was about the same elevation as the farm field the ditch was to irrigate. In one case, it would take 5 days to irrigate a small vegetable garden of about half an acre. A seven acre alfalfa field took about a week to irrigate, and even then the water would make it less than halfway across a 600 ft long field.

In the 1990's, Cochti Pueblo was at a low point in terms of practicing irrigated agriculture. After a lawsuit and 20 years in which an entire generation had lost the practice, expertise, infrastructure, and equipment for farming, the lands were finally drained. Diversions had been cut over the years so that there was inadequate head in some ditches to supply the fields. Farm ditches were poorly designed or not operable. Only a handful of farmers, whose fields had been high enough to farm through the years of partial inundation from Cochiti Dam, continued to farm. Funds through the Bureau of Indian Affairs for irrigation had all but dried up, so that when Cochiti needed BIA funds to rebuild after 20 years, no funding was available.

The desire to see farmlands restored and for farming to once again be the center of Cochiti's culture remained strong with elders of the Pueblo de Cochiti. As the BIA was no longer funding irrigation, the Pueblo attempted to work with the Bureau of Reclamation to rehabilitate and modernize their irrigation facilities. Unlike the BIA, Reclamation does not have a specific authority to work on Indian farm infrastructure. However, Reclamation does have multiple programs from which Cochiti Pueblo was able to secure funding. These included the Middle Rio Grande Project, the Native American Affairs Technical Assistance Program, and the Water for America Program, then known as Water 2025. The Pueblo has also been able to leverage Reclamation funds with other programs offered by the BIA, Natural Resources Conservation Service, and the Middle Rio Grande Conservancy District to obtain even more funding.

INFRASTRUCTURE IMPROVEMENTS

At first, the governor and tribal council wanted to restore old Indian earthen farm ditches to working order. This would allow the traditional cleaning of the ditches to take place in the spring. Reclamation's first improvements were to create new ditch berms and cut a ditch through the new berm using a grader. One ditch so constructed worked fairly well because old check structures were still in existence to drop the water from one terrace to another and control erosion. Even with this ditch, gophers proved to be a big problem. Funding was not available to build check structures on some other ditches, so there were big erosion problems when these earthen ditches dropped from one terrace to another. Maintenance of these earthen ditches also proved problematic. Since so few people were farming, there was little to no interest on the part of most pueblo members to clean ditches, and the ditches were too much for just a handful of farmers to maintain.

After this experience, the pueblo decided to try concrete lined ditches. One farm ditch was concrete lined by hand, using a "panel" method whereby the ditch was shaped and then forms were constructed across the ditch at 8-ft intervals (Figure 5). These forms, built of 2-in by 4-in lumber, would be poured in alternate fashion. Braces and stakes for the forms would be on the outside of the forms. Every other panel was poured, using the forms to screed the concrete. Then when the forms were removed, and the previously poured concrete panels were used as a form for screeding when the alternating panels were poured. Concrete was formed by hand around turnouts. While this method produced a very nice, workable ditch, it proved to be highly labor intensive and costly.

Trenched and slip-formed concrete ditches were tried next (Figures 6 and 7). The local NRCS office maintains a list of contractors who can do various types of irrigation infrastructure construction. With their information, a contractor was located. One ditch was constructed where there was only 2 ft of head between the checked water surface in the main canal and the farm field. The ditch constructed was 28-in high with a 2-ft bottom width, had 1.25:1 (horizontal to vertical) side slopes, and was 2.5-in thick. A 30-inch turnout from the canal was used with an HDPE pipe to minimze head loss through the turnout pipe. Twelve-inch diameter slide gates were spaced about 65 ft apart in the ditch. As the field had been previously leveled by the BIA, no additional laser leveling was done. Other ditches have been up to 38-in deep, and design thicknesses have increased up to 3-in. Actual thicknesses have ranged up to 4-in.

Because of natural terracing, the main canal is often 10 to 30 ft over some of the farm fields it supplies. As such, the land is ideally suited for irrigation pressure pipe systems. Because no earthwork was needed to build a ditch berm, the total cost for a pipe system is about half the cost of a slip-formed concrete lined ditch. Drop structures at terraces

Figure 5. The “panel” method of constructing concrete lined ditches.

Figure 6. Trenching a ditch berm prior to concrete slip forming.

are not needed with a pipe system, resulting in additional savings compared to a concrete lined ditch. Hardly anyone at the pueblo was familiar with the technology. The

Figure 7. Slip-form method of concrete ditch lining.

tribal council was reluctant to try such a non-traditional method, but decided to try it on a limited basis to see how it worked. Rather than taking water from lower laterals, the pipes were connected to the higher main canal. Pipes were 18-in diameter, 80 psi PVC PIP (polyvinyl chloride plastic irrigation pipe). Designs were invariably inlet control, and design flows were about 9-11 cfs. Overflow valves were spaced at 50 to 65 feet, depending on terrace width. Lands were laser leveled if needed. The NRCS WINsrfr[10] program was used, together with soil information provided by the local NRCS office, to design the most water efficient field given the crop type, water supply, and soil type.

The pipe systems proved to be highly effective. They were also popular since no labor-intensive cleaning was needed, as with ditches. However, they could not be used in locations where there was insufficient head between the supply ditch and farm field. In such locations, either a concrete lined ditch or high flow turnout would be required.

The NRCS had been experimenting with a new technology known as high-flow turnouts. They are feasible where a field is adjacent to or close to the water supply ditch, and where the crop to be grown lends itself to flood irrigation. Fields up to 15 acres have

[10] http://www.ars.usda.gov/services/software/download.htm?softwareid=250

been served by a single high flow turnout. The field is leveled either flat or with a very small slope to allow the water to spread evenly over the field. A stilling basin is constructed on the field side of the turnout to still the waters and prevent farm field erosion. Farm field turnouts are usually large, often 24-in or 30-in in diameter.

Figure 8 shows a typical NRCS design for a high flow turnout. It consistes of a concrete apron with concrete cinder blocks set in the concrete apron to act as baffle blocks, slowing the water. The concrete is not reinforced. The apron width at the end is about 15 ft. NRCS has reported some problems with breakage of the baffle blocks. However, the design requires no special formwork or machinery, so that any farmer or contractor should be able to construct it. Although it depends on the water supply and size of fields, the NRCS design flow for such a turnout is typically about 15 cfs.

Figure 8. NRCS designed high-flow turnout.

Figure 9 shows a high-flow turnout designed by the author. The contractor hired by the pueblo also builds houses, and has prefabricated forms for house foundations that can be readily adapted for high flow turnouts. The maximum height of wall that can be built using the contractor's forms is 2-ft, so the high flow turnouts were designed to accommodate the forms. No. 4 rebar is spaced at 1-ft on the floor and walls. These turnouts are 10 ft long by 8 ft wide, with 8-in wide walls and floor, and are 2-ft deep at the front and back. The wall elevation at the front and back is about level with the farm field. Because the field which is served by this turnout is relatively wide but not very long, the walls on the sides are only 1.5 ft high and 0.5 ft below the farm field elevation in order to try and force the water out the sides. The turnout is a 24-in diameter gate set in a concrete lined lateral. The bottom of the turnout pipe is 2-ft below the farm field elevation, and the top of the turnout pipe is at the farm field elevation. The farm field is sloped at 0.0002 ft away from the turnout. This design works well in preventing erosion and is easy to build for the contractor. Because of the contractor's expertise, it is easy and economical to build.

Figure 9. High-flow turnout designed by the author.

In general, the most economical structures are high-flow turnouts, followed by pressure pipe systems, followed by concrete lined ditches. All can be made equally water efficient with proper laser leveling. However, the type of structure used must conform to the expected crops to be grown, the amount of head available, the water supply, and the amount of terracing in the fields to be served. High flow turnouts or concrete lined ditches must be used where head is limited. Concrete lined ditches or pressure pipe systems should be used if there is a possibility of growing row crops. High flow turnouts, pressure pipe systems, or concrete lined ditches can be used for non-row crops such as alfalfa, pasture, oats, etc. Pressure pipe systems are best when there is a lot of head, usually at least 3-ft to 4-ft depending on the length and diameter of pipe.

The slip form used can vary the depth of ditch depending on required flows, but not the side slope or bottom width. The maximum depth is about 40 inches. A different trencher and slip form is required to vary the side slope and bottom width.

Other cost savings measures include minimizing terrace heights (Figure 10), using ramp flumes for check structures (Figure 11), and reversing gradients on some fields to reduce the number of concrete lined ditches needed (Figure 12) .

Figure 10 shows how terrace berms were created in such a way as to increase irrigation efficiency and minimize the amount of terracing and laser leveling required. The blue arrow shows the old direction of irrigation, along a slope of 0.01 ft/ft, or 1 ft per 100 ft. This is far too steep for the higher flows possible with a pipe system. To prepare for the new pipe systems, fields were terraced along natural contour lines with widths of about 120 ft, so that terrace heights were roughly 1 ft high, minimizing the amount of earthmoving necessary. The green arrow shows the location of a new pressure pipe alongside a newly constructed 2-ft high access road. T-sections coming off the pipe allow irrigation of fields on both sides of the road, in opposite directions. New fields vary from 700 to 1100 ft in length, with 0.0002 ft/ft slopes to maximize efficiency given the flows and soil type.

Figure 10. Terrace berms and roads.

Figure 11 shows a ramp flume which is used as a check structure[11]. While designed primarily for water measurement, it allows water to be checked at all times to a minimum elevation. It requires no operation, so there is no possibility of operator error such as leaving a gate down in a traditional check structure after irrigation, causing a ditch

[11] Ramp flumes can be designed using free software named WinFlume available from the U.S. Bureau of Reclamation at http://www.usbr.gov/pmts/hydraulics_lab/winflume/

overflow. Water flows from left to right in the photo. A 4-inch PVC pipe at the base of the ramp flume allows water upstream of the flume to be drained out. The ditch height is 38 inches with a 2-ft bottom width and 1.25:1 (horizontal to vertical) side slopes, and ramp flume height is 19 inches. The ditch design flow is 25 cfs, which can be accomodated by the ramp flume with adequate freeboard.

(a)

(b)

Figure 11. (a) Ramp flume used as check structure in a concrete lined ditch. (b) Ramp flume in operation.

Figure 12 shows how reversing the slope on some irrigated fields can reduce the amount of irrigation infrastructure necessary. The new concrete lined ditch can be seen on the upper terrraces (toward the bottom of the photo). At the end of the new concrete lined ditch, a pipe system begins to service the lower terraces (toward the top of the photo). Previously, each row of fields had its own ditch (shown in purple) and all fields irrigated from north to south (blue arrows). Now, half the fields have been resloped, so that each ditch and pipe system can irrigate both to the north and the south (red arrows show new direction of irrigation). By doing this, the number of ditch/pipe systems necessary to replace old ditches was cut in half. Replacing ditches with pipe systems on lower terraces also added to the savings. All fields were laser leveled.

CONCLUSION

Improving the irrigation efficiency of the six Middle Rio Grande pueblos is more important than ever, given the ever-increasing demands on waters of the Rio Grande by other users, including endangered species. At the Pueblo de Cochiti, the Bureau of Reclamation had an opportunity to essentially start over with a pueblo irrigation system. Improvements and incorporation of modern technology, such as concrete ditch lining, implementation of pressure pipe and high flow turnout systems, proper laser leveling, terracing, and the use of soil science, together with farmer education, can greatly improve irrigation efficiency and production. Irrigated agriculture is central to Pueblo culture. In earlier times, pueblo members were mostly full time farmers, and supported their families by practicing highly labor intensive subsistence agriculture. Today, most Pueblo members work outside at jobs both at the pueblo and outside the pueblo, leaving far less time for agriculture practiced with labor intensive methods. By being open to new technology where farming can be done more profitably in much less time, the Pueblo de Cochiti is assuring itself that irrigated agriculture can continue to be practiced, preserving not only farming but their culture.

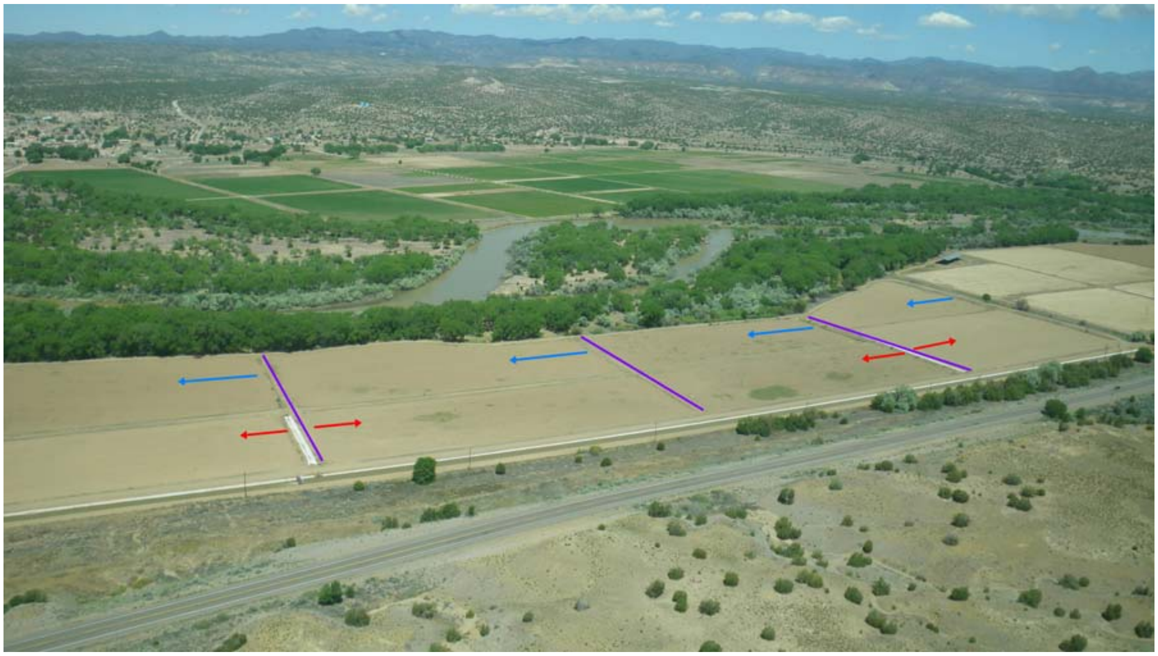

Figure 12. Reversing irrigation direction.

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The author wishes to thank members of the Pueblo de Cochiti, who have been a delight to work with over the last 11 years. Especially deserving of credit is Lee Suina, who was invited to be a co-author for this paper. His untimely death due to a brain tumor in March 2011 at the age of 32 was a tremendous loss to his family, friends, and the entire Pueblo de Cochiti. The unflagging commitment and vision of Lee Suina and Jacob Pecos to restore and modernize irrigated agriculture at the Pueblo de Cochiti is chiefly responsible for the irrigation infrastructure improvements described in this paper.

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DIXIE VALLEY, NEVADA GROUND WATER EXPORT STUDY

Mark Spears, PE[1]

ABSTRACT

In 2008, Public Law 110-161 authorized $5,000,000 for the Bureau of Reclamation to "study and prepare plans for the development and construction of a pipeline to convey water from Dixie Valley to Churchill County, Nevada." The 5-year study is being performed by a multi-agency study team with completion scheduled for 2013. It includes hydrologic analyses, ground water modeling, design and construction cost estimating, and environmental and economic analyses components. Preliminary hydrologic data indicate sufficient water of adequate quality is available for potential export. These data and ground water model results will provide the basis for determination's by the Nevada State Engineer's Office on the proposed trans-basin export of Dicie Valley ground water. The ground water model results will also guide the development of designs and cost estimates for the proposed project. At a minimum, the proposed project will include a field of 10 or more wells, 70 miles of pipeline, and pumping and treatment facilities. Hydropower and pump-storage facilities will also be considered. The environmental analysis will identify potential impacts and provide a road map for complying with state and federal requirements if the project moves forward. The economic analysis will evaluate various scenarios focused on potential uses for the exported water.

The study results are intended to provide a sound basis for decision-makers when considering the export project as an option to help address the significant water shortage conditions of Nevada's Truckee and Carson River Basins.

INTRODUCTION

The Consolidated Appropriations Act of 2008 (Public Law 110-161) authorized $5,000,000 for Reclamation to "study and prepare plans for the development and construction of a pipeline to convey water from Dixie Valley to Churchill County, Nevada." The funding was provided through Reclamation's Desert Terminal Lakes Program which is administered by the Lahontan Basin Area Office (LBAO) in Carson City, Nevada. The Program Manager requested that Reclamation's Technical Service Center (TSC) in Denver, Colorado provide assistance with study planning and execution. The study is being conducted by a multi-agency study team lead by the TSC. Study team agencies include Churchill County, Nevada Division of Water Resources (NDWR), U.S. Geological Survey (USGS), and Reclamation.

The primary purpose of the study, as defined by the study team, is to quantify the amount of ground water that could be exported from Nevada's Dixie Valley and develop pipeline and appurtenances designs and cost estimates to convey the exported water to locations within or nearby Churchill County.

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Study objectives include quantifying the valley's perennial yield based on ground-water discharge evaluations, analyzing the impacts of exporting specific quantities of ground water, and performing economic analyses of various water export scenarios.

Study scoping activities were concluded in November 2008 and the study's first of three phases was initiated December 2008. Phase 1 includes research, data collection and analyses to estimate perennial yield and develop the hydrogeologic framework necessary to develop ground-water models and analyze the proposed export project. Ground-water modeling will be done during Phase 2, and project design and cost estimating and environmental and economic analyses will be done during Phase 3. Phase 1 is nearing completion at this time and Phases 2 and 3 are schedule for completion in 2012 and 2013, respectively.

BACKGROUND AND STUDY AREA

Dixie Valley is located mostly within Churchill County in west central Nevada as shown in Figure 1. The county population of approximately 30,000 is centered around the City of Fallon, which is the county seat. It is a primarily agricultural area and Reclamation's Newlands Project provides irrigation water for about 50,000 acres around Fallon. The Naval Air Station Fallon (home of "Top Gun") is located a few miles southeast of the center of Fallon. Dixie Valley is used for flight training by Naval Air Station Fallon.

There is also extensive geothermal resource development underway in Dixie Valley. The valley is home to one of the most potentially important geothermal resources in the U.S. Terra-Gen Power, LLC owns and operates a 67 megawatt plant in Dixie Valley and is pursuing further development of the resource in the valley. The Navy is also currently collecting geothermal development data in the valley.

The southern end of Dixie Valley is located about 30 miles east of Fallon in the adjacent drainage basin. Dixie Valley has an area of about 1,300 square miles with the Stillwater Mountains on the west side of the valley and the Clan Alpine Mountains on the east. There are only a few people that reside in Dixie Valley (current estimate is 5).

The study area includes Dixie Valley and the six other NDWR administrative ground-water basins that are considered to be part of the same ground-water flow system and contributory to the Dixie Valley ground-water basin. The northern portion of the Dixie Valley ground-water basin is in Pershing County, and the southern portion of the adjacent Fairview Valley ground-water basin is in Mineral County. The remainder of the study area is in Churchill County.

Previous studies indicate that ground water flows into Dixie Valley from all of the adjacent basins (Cohen and Everett, 1963 and Harrill and Hines, 1995). Dixie Valley is a closed basin and all discharge is by evapotranspiration (ET) and evaporation. A large source of evaporation is from the playa located in the central portion of the valley which is known as the Humboldt Salt Marsh. The surface area of the playa is approximately 44,000 acres. The playa is typically covered with water during winter months and

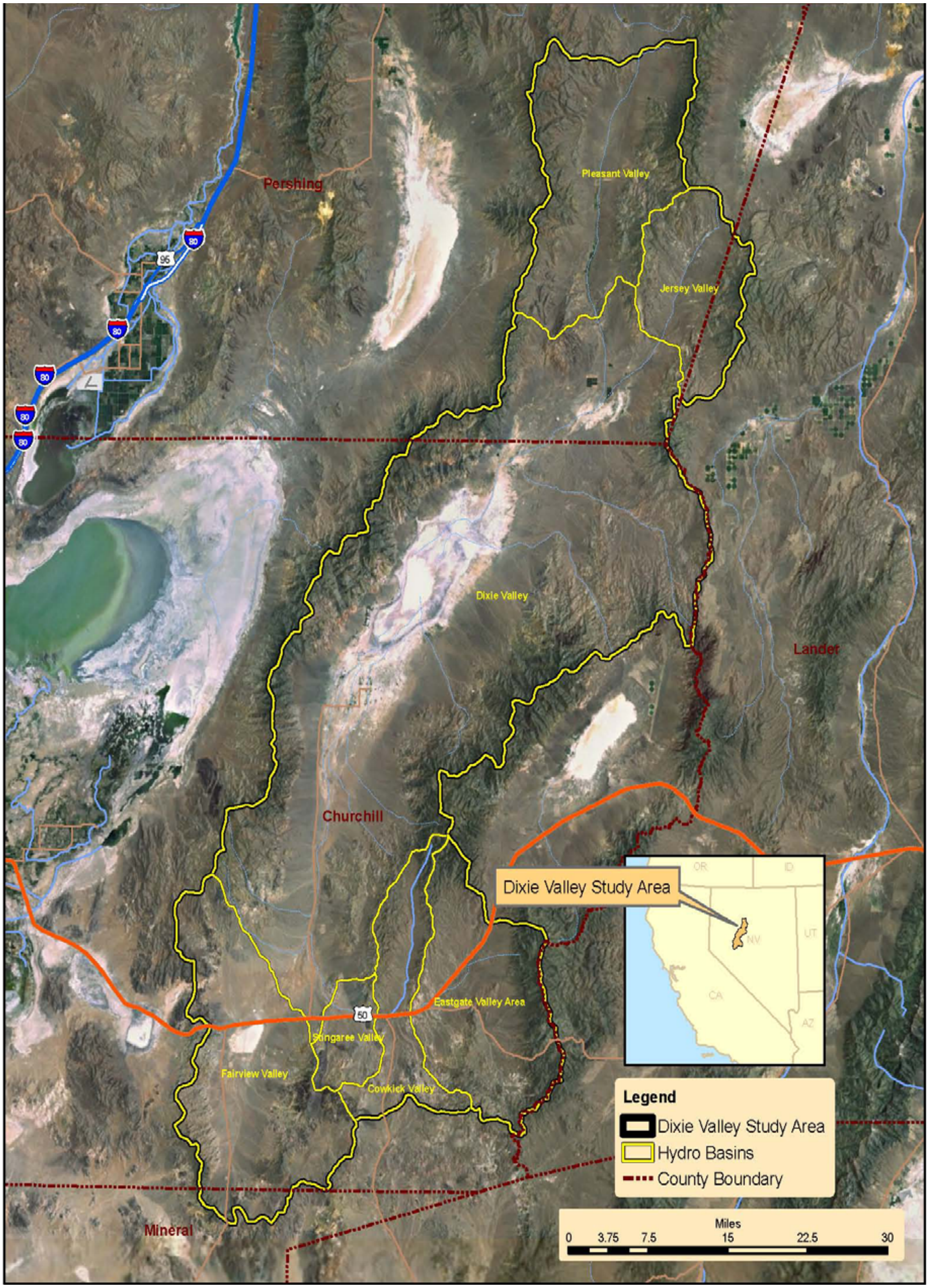

Figure 1 – Dixie Valley Location Map

although the standing water evaporates during late-spring, the center portion of the playa surface remains moist year-round.

Prior to commencement of the Naval Air Station Fallon's flight training in Dixie Valley, an irrigated agriculture settlement area had become established in the south-central portion of the valley. The Navy purchased these irrigators' lands and acquired the associated water rights during the 1980s. Since this time, the Navy has attempted to lease these lands for irrigated agricultural purposes and protect the water rights. These efforts have been generally unsuccessful and some of the water rights have been forfeited or cancelled in recent years.

The potential export of Dixie Valley ground water has been studied for over 30 years. Study findings reports include Westpac Utilities (1987), WRD (1992), Reclamation (1993), SPPCo (1994), WRD (1996) and WRD (2003). The USGS has completed two Dixie Valley hydrogeologic studies that yielded estimates of perennial yield; Cohen and Everett (1963) and Harrill and Hines (1995).

Churchill County has pending water rights applications for 56,472 acre-feet of Dixie Valley ground water with 1985 priority dates. Churchill County's current Water Resource Plan (WRD, 2003) identifies the need for a rural water supply and distribution system, and it identifies Dixie Valley exported ground water as a potential supply source.

The City of Fallon has also been identified as a potential user of exported Dixie Valley ground water. Fallon's municipal water supply is ground water pumped from a basalt aquifer. Although past problems with arsenic levels have been remedied with a new water treatment facility, there are concerns about the long-term viability of this water supply source due to reduced aquifer levels and increases in chloride concentrations (USGS, 2002). Most Churchill County residents outside the city limits get water from shallow individual wells, many of which provide poor quality water. The county's new water system provides treated water from the extensive intermediate aquifer that exceeds all state and federal drinking water standards, though less than 500 residents and businesses are currently served.

In the event the Dixie Valley ground water export supply significantly exceeds the needs of Churchill County, the surplus water could potentially meet other demands outside of the county (e.g. Fernley and Carson City in Lyon County). This could be accomplished with additional pipeline construction or through water exchange agreements.

If the study shows an adequate quantity of ground water can be exported without negative impacts to environmental or geothermal conditions, it is anticipated that Churchill County will seek approval for all or a portion of its water rights applications and secure funding to finalize planning and engineering and construct the export project.

STUDY DESCRIPTION

This description focuses on the Phase 1 activities that have been ongoing for over 2 years with a brief discussion of the recently initiated Phase 2 and planned Phase 3 activities. The primary components of the Phase 1 effort include the following:

- High-altitude precipitation data collection and analyses;
- Streamflow data collection and analysis;
- Ground water discharge estimation;
- Wells and springs inventories and sampling;
- Evaluate ground water quality and geochemistry;
- Research geothermal industry information;
- Develop hydrogeologic framework; and
- Complete water rights abstract.

Each study team entity prepared detailed work plans for the study components it participated in. The individual entity work plans provided the basis for an overall study work plan. The work plan and status of each of the above study components are discussed below.

High-altitude Precipitation Data Collection and Analyses

Churchill County has established a precipitation station network in the mountains surrounding Dixie Valley. The network of 12 stations provides data to associate climate related effects to key hydrologic resources in the valley. It will be maintained through the study period and kept in place for continued data collection after the study.

Once a long-term precipitation dataset is developed, short-term and long-term water level, spring discharge, and stream flow trends that are climate-related can be more conclusively identified and segregated from potential effects of well field pumping. The precipitation data should also be of value in assessing any variances observed in spring flows, runoff, and groundwater level fluctuations observed during the study period.

Water samples from the precipitation gages will be analyzed for chloride content in precipitation and dry-fall. These data will provide a means to make independent ground water recharge computations, using the chloride-mass balance technique.

The water samples will also be analyzed for stable isotopes levels. These data will be evaluated relative to stable isotopes data from mountain front springs and valley bottom plant water extractions. The findings if this work will be incorporated into the Phase 2 ground water modeling effort and the results will be presented in the associated model documentation report.

Streamflow Data Collection and Analysis

Streamflow measurements are being made by Churchill County using various methods in order to collect data on stream discharges at the mountain fronts, from tributary basins, and into the playa. These data are being evaluated in an attempt to quantify the amount of surface water that runs on to the playa. Stream flow losses on the alluvial fans and valley floor are also being evaluated.

Methods being used for stream gaging include rating channel sections equipped with continuous stage recorders, miscellaneous measurements by current-velocity meters, and indirect computations using channel geometry for high flow events.

An initial canvass was made to inspect major drainages, indentify perennial stream segments, and identify suitable gage locations. Stage recorders were set at locations in ephemeral stream beds, including 13 at or near the playa edge and 10 locations near the mountain front boundaries to the basin, at major drainages into the valley, and at lower alluvial fan locations. Channel cross-sections and gradients were surveyed at the stage recorder sites, and discharge hydrographs have been developed and volumetric discharge computed using Manning's equation. Field observations have been made during significant runoff events.

Preliminary findings indicate that snow melt and rain event run off quantities reaching the playa are relatively small (less than 500 acre-feet per year). Data collection will continue through Spring 2012 and a stream flow analysis report will be published by Curchill County's consultants in 2013.

Ground Water Discharge Estimation

Dixie Valley perennial yield is equal to the amount of ground water that evaporates from the playa plus the ground water consumed by phreatophyte ET minus the quantity of ground water from the contributory basins. The two primary ground-water discharge areas (playa and phreatophyte) have been delineated using remote sensing and field checks. USGS and Reclamation will independently calculate discharge for the phreatophyte area by two different methods using a combination of onsite and remote sensing data. USGS and Churchill County consultants will independently calculate discharge for the playa area by two different methods also using a combination of onsite and remote sensing data.

Four eddy covariance (EC) type micrometeorological stations were installed in March 2009 (two playa sites and two phreatophyte sites) to measure real time evaporation and ET. Data collection at these sites was completed in Fall 2011 providing 2 complete water years worth of data.

The EC stations provide information about the magnitude and spatial and temporal variability of evaporation and ET. Precipitation and ground-water levels were also monitored at each EC station. Periodic portable chamber (ET dome) measurements of bare-soil evaporation were made to further capture spatial variability across the playa surface and provide insight into the bare-soil contribution to ET measured in vegetated areas. Matric potential profiles determined using heat dissipation sensors are being used to evaluate seasonal water flow directions throughout the unsaturated zone beneath vegetation and within the playa at each EC site. Stable isotopes analyses are being used to quantify the relative proportions of source waters in plants and playas at each EC site. In vegetated areas, plant-stem water from dominant species, ground water, shallow soil water, and recent precipitation was sampled during the spring, summer, and fall seasons and analyzed for oxygen-18 and deuterium. In playa areas, soil water profiles, ground water, recent precipitation, and existing surface water was sampled quarterly for isotopic composition to determine the source water near the evaporating surface and the evaporation extinction depth. Simple mixing models are being used to partition source water.

USGS will delineate the primary discharge areas into ET units distinguished by vegetation type and density, and soil properties. ET units will be delineated from Landsat imagery based on Modified Soil Adjusted Vegetation Index (MSAVI) values in vegetated areas and Tasseled Cap Transformation values in playa areas. Average annual ET and evaporation rates will be developed for each ET unit based on EC and ET dome data. Total ground water discharge will be estimated by multiplying the ET and evaporation rates by the land areas associated with the respective ET units.

Reclamation will calculate discharge for the phreatophyte area using a relatively new method known as NDVI* (Groeneveld et al. 2007). This method is based on a "stretched" form of the normalized density vegetation index (NDVI) and reference ET. The NDVI* method will be applied to a series of historical Landsat images representing wet, dry and normal conditions. The results of this method provide an annual ET estimate for each 30 by 30 meter Landsat image pixel and summation provides the total annual phreatophyte ET estimate.

Churchill County's consultants will quantify playa evaporation with another new method using Landsat Band 5 data from a series of images representing wet, dry and normal conditions. The data will be evaluated to calculate playa evaporation as a factor of the incident light absorbance by water at the soil surface. An index value is calculated for each image pixel, similar to the NDVI* method, that is applied to reference ET. The total evaporation quantity will be portioned into surface and ground water by evaluating precipitation and playa runon relationships using remote sensing data.
HydroBio will complete its work and publish playa ground water.

The USGS results will be included in a scientific investigations report; the Reclamation results will be published in a technical memorandum; and the work by Churchill County's consultant will be published in a peer reviewed journal article. All three of these reporting documents will be published in 2013.

Wells and Springs Inventories and Sampling

The data from this task will be used to update potentiometric mapping, interpret subsurface flow systems, understand seasonal water level variations, and indentify long-term water level trends. It will also be used for future model calibration and to document pre-development baseline water level conditions.

Existing information on all known wells and springs located in the Dixie Valley and adjacent basins has been compiled and physical inventories were conducted. The sources of existing information include NDWR (State Engineer's Office), USGS National Water Inventory System (NWIS), Navy Air Station Fallon and the BLM. Examples of existing information compiled are water right applications, well permits, well drilling logs, proofs of completion, proofs of beneficial use (PBU), certificates, PBU and permit maps, rulings and orders, and historical water level measurements.

These documents were reviewed for information useful in characterizing aquifer properties, depth and extent of subsurface aquifers, perforated intervals, historical water levels, irrigated acreages, locations of historical use, etc. Drilling logs and PBUs sometimes have flow rates and draw-down measurements from which aquifer parameters are estimated. Since nearly all of the irrigated rights were certificated before the Navy buy-out, PBU maps should provide a good historical irrigated acreage to which consumptive use estimates can be applied to arrive at historical net irrigation pumping demand.

Depth to groundwater measurements were made at those sites in the NWIS database that could be identified in the field, with supplemental measurements from other wells located via the NDWR database. Field measurements include static water, measurement point reference height, well diameter and handheld global positioning system (GPS) location coordinates. For flowing wells, discharge rates and shut-in pressure heads were obtained, to the extent that casing and ground conditions support. Field parameters of temperature, conductivity and pH were made with a multi-probe, and samples were collected and delivered to an analytical laboratory for general mineral content, Profile I metals, and radioactivity parameters, bromide, silica and stable isotopes (oxygen-18 and deuterium).

Once the well inventory was done (approximately 75 wells), a subset of wells was identified for ongoing monitoring of water levels and flow rates. The monitoring subset includes approximately 40 wells. Quarterly measurements were made through Fall 2011 and semi-annual water level monitoring will continue through Fall 2013.

Four nested piezometers were installed on the playa to compliment those installed at the EC stations. The deep and shallow piezometers allow vertical gradients to be measured and to assist in quantifying playa evaporation and depth to water.

The springs inventory was conducted during July 2009 to September 2009 prior to any significant winter-time precipitation. Summer-time sampling was desired to avoid potential comingling of deep versus perched or shallow groundwater sources that may be ephemeral in nature. The inventory included flow rate, general conditions, and field parameters (pH, conductivity and temperature), and samples were collected for minerals and stable isotopes analyses. Most BLM springs of significance were inspected (22 springs). These springs include primary geothermal springs in the study area, and significant valley floor and mountain front springs that have historically provided water sources for wildlife, stock, and other purposes. The BLM springs of significance typically represent the largest discharge springs in the region. Discharge is being monitored quarterly at 9 selected springs through June 2012.

In order to perform the previously mentioned chloride mass-balance evaluation, additional spring water chemistry data are needed. Spring data collected at the mountain front from BLM springs of significance will provide some data on groundwater chloride content; however, additional samples from mountain-block springs were collected and analyzed for general chemistry including chloride, along with bromide, silica, and stable isotopes (oxygen-18 and deuterium). Eleven additional mountain block spring samples were taken.

All wells and springs data have been entered into the USGS National Water Information system data base (http://wdr.water.usgs.gov/nwisgmap/) and a springs' inventory report will be published by Churchill County's consultants in 2013.

Evaluate Ground Water Quality and Geochemistry

Water quality of the basin fill aquifers is being characterized by the USGS using existing chemical data and by collecting and analyzing major ions, silica and other important constituents from ground water and springs throughout the basin. Initial water sampling during Fall 2009 included a large suite of chemical constituents from 31 sites. Follow-up samples were taken during Spring 2010 at 19 of these sites. Constituent concentrations are being compared with National primary and secondary drinking water standards to evaluate the potability of the ground water. Geothermometry with major ions and silica will be used to estimate temperatures throughout the basin and identify geothermal contributing zones. Past investigations have documented high levels of dissolved solids and fluoride. Characterization of ground-water quality will also provide a basis for conceptual model development and offer insight into appropriate ground-water modeling methods.

Preliminary ground water quality findings regarding domestic use are favorable and this will be further evaluated with the solute transport component of the ground water model. All water quality analyses results will be included in a USGS scientific investigations report to be published in 2013.

Research Geothermal Industry Information

The objective of this task is to understand the extensive geothermal systems in Dixie Valley and how they may or may not interact with the non-thermal ground water systems.

There are several geothermal systems in Dixie Valley including the Eleven Mile Canyon and Pirouette Mountain geothermal systems in the southern part of Dixie Valley; the Dixie Hot Springs and Dixie “South” geothermal systems in the central part of Dixie Valley; the Dixie Valley geothermal field and Dixie Caithness fields in the northern part of the valley; and the Sou, Hyder, McCoy, Lower Ranch, and Jersey Valley geothermal systems in the northern part of the valley. All published geological, geochemical, and geophysical reports and papers have been incorporated into an overall synthesis of the geothermal systems in the area. This report (Benoit, 2011) presents the geologic framework associated with the geothermal resources in Dixie Valley, including interpretations of fault structures, flow systems, water origin, quantity of resource, quality, etc. It is being used by the study team in its efforts to understand the potential connections or lack thereof with basin fill aquifers and flow systems, and for the ground water modeling effort for simulations of potential impacts to or from existing and proposed geothermal resources.

USGS is conducting an analysis of existing geothermal related geochemistry data in an effort to better define the relationship between the deep geothermal and shallow fresh water aquifers. The results of this work will be included in a USGS scientific investigations report to be published in 2013.

Develop Hydrogeologic Framework

The USGS is developing the framework of the Dixie Valley subsurface flow system by identifying structural features, delineating the three-dimensional geometry of the subsurface basin fill aquifer(s), determining the hydraulic properties of the major hydrogeologic units, and identifying data gaps. Structural features controlling ground-water flow such as fracture networks have been identified using existing geologic data and geophysical surveys. The three dimensional geometry of the Dixie Valley flow system is being evaluated using existing geophysical data. The thickness, geometry, and structural disruption of the water bearing units will be mapped using existing gravity and aeromagnetic data. Hydraulic properties are being determined using lithologic logs, borehole logs, and aquifer test data. An aquifer testing program was developed based on existing information and implemented in 2010.

Ground-water levels in existing wells have been compiled, collected, and evaluated to determine the direction and gradient of ground-water flow, with careful consideration to the distribution of geologic features that may act as conduits or barriers to ground-water flow. A current potentiometric-surface map showing ground-water flow is being developed for the basin fill aquifer(s) and compared with historical maps to evaluate potential changes in ground-water flow and storage changes related to ground-water level trends.

Subsurface flow entering Dixie Valley from Pleasant, Jersey, Stingaree and Fairview Valleys will be estimated by applying Darcy’s Law and estimates of transmissivity, the effective width of unconsolidated sediments through which flow takes place and the gradient of the water table perpendicular to the outflow cross section. Isotopic samples of ground water, precipitation and springs will help constrain the estimated subsurface inflow. Ground-water samples have been collected both up-gradient and down-gradient from each of the six contributing valley outlets into the Dixie Valley basin. Analysis of isotopic data using binary mixing will help determine the fraction of subsurface inflow from each of the six contributing valleys. The hydrogeology of the Dixie Valley flow system will provide the foundation for development of a ground-water flow and transport model.

The hydrogeologic framework will be described by USGS in a scientific investigations report to be published in 2013.

Complete Water Rights Abstract

Churchill County's consultants will update the existing water rights abstract to determine the location, status and amount of spring, underground and surface water rights in Dixie Valley and the Tributary basins. This task will be completed near the end of the study period so as to provide the most recent analysis of committed rights verses un-appropriated ground water which will aid in determining the duty of water for the State Engineer to consider regarding issuing permits under Churchill County's pending applications to appropriate ground water exported from Dixie Valley.

All active spring, surface and underground water rights will be reviewed at the State Engineer's Office. Summary tables will be prepared by manner of use and source type for all water rights. Locations of points of diversion for each right will be incorporated into a geographic information system.

Numeric Ground Water Model Development

The Phase 2 ground water model development was initiated during Summer 2011. It is being performed by Churchill County's consultants with review and oversight by the other study team entities. The model will be sufficient to provide a means to evaluate the feasibility of water development, support review of pending water rights applications, and to form the basis for a model to be used for NEPA compliance.

The numeric flow modeling effort will compile the major components of the ground water studies that are on-going in Dixie Valley, along with relevant portions of previous published works, into a comprehensive representation of the Dixie Valley flow system. The model is planned to be a basin-scale effort, and will represent the water balance as defined by on-going studies of groundwater discharge by evapotranspiration and playa evaporation, and updated data on pumping, spring discharge and artesian well flows. Recharge distribution will be based on updated interpretations of subsurface inflows, infiltration of precipitation in surrounding mountains and in ephemeral channels in the basin, and possibly artificial injection (geothermal) back into the deep flow systems. The model domain will incorporate, at a minimum, the valley floor of Dixie Valley, and may also include mountainous watersheds and adjacent basins such as Fairview Valley and

Jersey Valley. The model will represent both shallow and deep flow systems, and will incorporate geothermal flow systems and high salinity groundwater considerations.

A draft conceptual model has been developed and is under review by the study team. Development of the steady state flow model will occur during 2012. Model tools include MODFLOW, GWVistas, PEST and SEAWAT. The model results and associated analyses will be included in the overall ground water model documentation that will be published in 2013.

Design, Cost Estimating and Environmental and Economic Analyses

The planned Phase 3 design, cost estimating and environmental and economic analyses work is on hold due to recent funding cuts. It had been envisioned that the design would include a field of 10 or more wells, 70 miles of pipeline, and pumping and treatment facilities. Hydropower and pump-storage facilities could also be considered. The environmental analysis would identify potential impacts and provide a road map for complying with state and federal requirements if the project moves forward. The economic analysis would evaluate various scenarios focused on potential uses for the exported water.

CONCLUSION

Upon study completion, it is intended the results will provide a sound basis for decision-makers when considering the export project as an option to help address the significant water shortage conditions of Nevada's Truckee and Carson River Basins.

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ENVIRONMENTAL COMPLIANCE FOR DIVERSION DAM REPAIR IN YOLO COUNTY, CA

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ABSTRACT

This presentation is a case study of environmental permit compliance for the construction of necessary dam safety repairs to a nearly 100-year old diversion dam in an environmentally sensitive area. Construction scheduling was further complicated by a short construction window due to irrigation demand and avoidance of seasonal streamflow during construction.

Capay Dam is a concrete irrigation diversion dam that was constructed on Cache Creek, a tributary to the Sacramento River, in California in 1914. Since construction of the dam, Cache Creek downstream of the dam was subjected to; extensive sand gravel mining, streambank encroachment due to agriculture and urban development, bridge construction, streamflow depletions due to irrigation diversions, groundwater declines, and other anthropogenic influences. As a result, streambed degradation of about 15 feet had developed immediately below the dam due to a combination of factors; probably most significant being the massive quantities of sand and gravel extraction to support urban development and transportation system construction in California, and that degradation was threatening the stability of the dam which was in danger of failure. The dam, owned by the Yolo County Flood Control and Water Conservation District, had only minimal maintenance during its long period of operation, although a 5-foot diameter rubber bladder had been installed on the crest of the nearly 500-foot long dam in 1993 to increase diversion capacity and to facilitate annual operational maintenance requirements.

Construction of necessary dam repairs in 2010 was complicated by three factors; 1) requirements to continue to divert water at the dam for irrigated agriculture through the middle of September, 2) a need to complete construction before the northern California winter storm season, and 3) compliance with several environmental and permit requirements. These factors restricted the construction window to eight weeks.

Environmental compliance included that of the US Army Corps of Engineers, 404 permit; US Fish and Wildlife Service biological opinion; California Department of Game and Fish; Central Valley Regional Water Quality Control Board 401 Certification; Stormwater Pollution Prevention Plan; and Valley Elderberry Longhorn Beetle and California Giant Garter Snake protection.

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The dam was successfully rehabilitated and should continue to provide irrigation diversions to a major agricultural area for well into the future.

INTRODUCTION

Agriculture plays a key role in Yolo County, California's heritage and economy. Almost 99 percent (more than 600,000 acres) of its unincorporated land is designated for agricultural use. The Yolo County Flood Control and Water Conservation District (District) provides irrigation water to about 60,000 acres. Depending on water supply in its two upstream water supply reservoirs (Clear Lake and Indian Valley Reservoir), the District releases about 250,000 acre-feet of water during the irrigation season. That water is diverted from Cache Creek into two main canals, the Winters Canal and West Adams Canal, at the Capay Diversion Dam. From Capay Dam, water from Cache Creek is delivered via nearly 175 miles of canals and laterals. The continued and reliable operation of Capay Dam is vital to the sustained future of irrigated agriculture in Yolo County.

Cache Creek is a valuable economic resource to Yolo county. Irrigation diversions began prior to 1850. Near the turn of the century, extensive canals and laterals were constructed to serve the agricultural demand. Besides water, Cache Creek is a major regional source of sand and gravel for the construction industry. Extensive rock product extraction from the creek accelerated in the 1950s. Cache Creek experienced streambed degradation from the mineral extraction which was exacerbated by other anthropogenic influences to Cache Creek. The geomorphic changes to Cache Creek resulted in streambed degradation at Capay Dam of more than 15 feet since the dam was constructed. In the 1990s, concern for Cache Creek resulted in a regional resource management plan that included management of sand and gravel extraction.

CAPAY DIVERSION DAM

Capay Dam is a concrete overflow diversion with headgates at each abutment. The Winters Canal headworks is in the right (look downstream) abutment and the West Adams Canal headworks is in the left abutment. The dam was constructed in 1914. The overflow section is 475 feet long with low-level sluice gates and service spillways near each abutment. As originally constructed, a short concrete apron extended downstream of the overflow section. the concrete overflow section is 10 feet high. The dam was originally fitted with timber flashboards that were repaired or replaced prior to each irrigation season. In 1993, a 5-foot high inflatable rubber bladder was added to the crest of the dam so as to improve the efficiency of irrigation diversions while maintaining the dam's historic flood discharge capacity.

In 2003, a section of the apron failed resulting in an emergency repair. The cause of the partial apron failure was not confirmed but was probably due to the combined effect of streambed degradation, scour at the end of the apron, and concrete erosion of the apron due to sediment impact.

DAM REHABILITATION

Inspections and engineering analyses of Capay Dam were conducted from 2006 to 2008. As a result, it was determined that a new, hydraulically efficient apron was needed and that a downstream grade control structure was necessary to protect the dam from threat of advancing streambed degradation below the dam.

Design of the dam rehabilitation was performed by Stantec in 2009 and construction documents prepared in 2010. The construction was bid by the District in the summer of 2010 and construction was performed from September through November of 2010. Major construction tasks included;

- Placement of 5,000 cubic yards of Roller Compacted Concrete (RCC) for the new apron and cutoff wall.
- Reinforced concrete sluiceway channels at each end of the apron.
- Concrete grade control structure about 150 feet downstream of the dam.

The construction was challenged by three factors:

1. The desire by the District to continue to deliver irrigation water and operate Capay Dam through 15 September.
2. The need to complete construction in November to minimize the risk of high flow in Cache Creek due to winter storms in the Coastal Range.
3. Environmental constraints regarding the construction start date and site dewatering of the site to protect threatened and endangered species.

The focus of this paper is the environmental permitting and subsequent compliance during construction.

ENVIRONMENTAL PERMITS, CONSTRAINTS, AND REQUIREMENTS

US Army Corps of Engineers 404 Permit

Compliance with the US Army Corps of Engineers 404 permit was typical for most projects. The Corps issued a permit (Nationwide Permit Nos. 3 and 27 for maintenance and stream and wetland restoration, respectively) for temporary and permanent impacts to waters of the US. The temporary impacts were from the staging areas and access road while the permanent impact was due to the increase of footprint of the dam apron. Mitigation was achieved by purchasing credits of riparian wetland habitat and open water channel habitat at a Corps approved wetland mitigation bank. In addition, the District was required to revegetate the disturbed reach of Cache Creek at a 2:1 ratio to shade the entire stream reach.

US Fish and Wildlife Service Section 7 Consultation

Due to the possible presence of giant garter snake and Valley Elderberry Longhorn Beetle (VELB), formal consultation with the US Fish and Wildlife Service was completed. The Giant Garter Snake (*Thamnophis gigas*) is a threatened species and the VELB (*Desmocerus californicus dimporphus*) is a federally-listed threatened species.

Giant Garter Snake. The giant garter snake is one of America's largest native snakes and is endemic to the California Central Valley. It originally inhabited wetlands and impacts to wetlands from agricultural and urban development has eliminated over 90 percent of the suitable habitat. Although the USFWS concurred that the project was not likely to adversely affect the giant garter snake, a pre-construction survey was performed 24 hours prior to the start of construction activities to ensure construction would not affect the giant garter snake. Furthermore, there were limitations to dewatering based on preventing impacts to the giant garter snake. Areas that were dewatered were required to remain dry (with no puddle water) for at least 15 consecutive days before workers could excavate or fill the dewatered habitat. Any prey (e.g., fish, tadpoles, aquatic insects) had to be netted and removed from the area.

Valley Elderberry Longhorn Beetle. The Valley Elderberry Longhorn Beetle is native to the riparian forests of the California Central Valley. The VELB is nearly always found on or near its only host plant, the elderberry plant (*Sambucus* sp.). Due to the location of numerous elderberry plants within the project area, the project was identified as likely to adversely affect the VELB and the USFWS issued a Biological Opinion regarding the VELB. The elderberry plants were adjacent to the access road and two plants were located within the staging areas for the project. Mitigation for impacts to the VELB was accomplished with avoiding and minimizing impacts with fencing as well as 24 elderberry plantings and 44 associated native plantings on no less that 0.28 acres. The mitigation items that affected construction included the following:

- 8 ft high plywood was placed around the two elderberry plants located within the staging areas
- Orange construction fence was installed 20 feet from the driplines of the elderberry plants along the access roads. Therefore, the alignment of the access roads was modified in some locations to achieve the required setback. In one stretch of access road, the road had to be realigned into the adjacent farm field and the District was required to mitigate (pay) the landowner for the impacts to the crop.
- Signs were erected every 50 ft along the fencing of the avoidance area to identify it as an avoidance area and notify that "violators are subject to prosecution, fines, and imprisonment."
- A Worker Environmental Awareness Program (WEAP) was initiated to educated the workers about the status of the VELB and the need to protect the elderberry plants, including the possible penalties for not complying with the requirements. The WEAP was provided when new crews arrived at the construction site.

California Department of Fish and Game Stream Alteration

The California Department of Fish and Game issued a Stream Alteration Agreement for impacts to Cache Creek. The Department of Fish and Game required mitigation at a 1:1 ratio for the temporary loss of 0.34 acres of riparian habitat (from the staging and access areas). The largest impact to construction of the Stream Alteration Agreement was that work was restricted to periods of low stream flow and dry weather between September 15 to November 10. Due to difficulties in maintaining a dry work area, on November 9 the District requested an extension to continue work in the stream zone until November 23.

California Regional Water Quality Control Board 401 Water Quality Certification

The California Regional Water Quality Control Board, Central Valley Region issued a 401 Water Quality Certification for the project. The 401 Certification required implementation of an effective combination of erosion and sediment control practices. To ensure the erosion and sediment control practices were effective, the District was required to perform water quality testing for turbidity and settleable solids. Water quality measurements were required every four hours during in stream work.

CONCLUSION

As a result of the numerous environmental permits, constraints, and reporting requirements, the District elected to maintain a full time environmental inspector on site during construction. At the onsite of construction activities, the environmental monitor ensured the elimination of Giant Garter Snake prey and performed water quality testing. During construction, the primary activities included insuring effective erosion and sediment control practices were being implemented and continuing water quality testing.

Despite the numerous permitting agencies and regulatory requirements, the project was able to be constructed efficiently due to the open and timely conversations between the District and the agencies.

ACKNOWLEDGEMENTS

We would like to acknowledge the Yolo County Flood Control and Water Conservation District staff, in particular Stefan Lorenzato, for effectively coordinating between the District and the regulatory agencies.

MORE CROP PER DROP: TRUE SUCCESS STORY OF JAIN HILLS

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ABSTRACT

Jalgaon — drought prone zone, scorching sun with extreme of 48^0 C and 5^0 C and an average rain fall of 600 mm, where cash crops are grown in rainy season only. In 1988, Jain Irrigation had started agriculture at1000 acres hilly barren stony terrain (Jain Hills) with literally no soil and water. Help from satellite and ground water survey did not reveal significant water aquifers so the option of drilling wells wasn't justifiable.

Alternatively, river 'Girana' remains dry for six months, and is too far from the farm to economically bring water to the farm. In short, other than limited rain water, there is no alternative assured source of water available at Jain hills. It was a challenging and risky job to do agriculture without an assured water source.

On investigation and reconnaissance, we found, a tiny stream adjoining the hills proceeding to river during rainy season, was the only ray of hope for creation of a water source for sustainable agriculture. And every drop of rain water counted and was harvested to get more crops. Hence, it becomes our registered trade mark *More Crop Per Drop*(R).

In this article, a case study has been presented in the latest trend of Agro-Business (debit-credit) Balance sheet to get the dynamics at a glance and scaled to 1 ha resultant of water availability and return on investment (ROI) before and after water harvesting.

ENGINEERING APPROACH

The following engineering approach was followed for creation of a water source and establishment of agriculture at Jain Hills.

Preliminary Survey and collection of data.

1. Topographical contour survey of entire terrain.
2. Meteorological data - temperature, relative humidity, rain, evapotranspiration.
3. Collection of soil samples and testing in laboratory.
4. Collection and study of agricultural and cropping details.

Planning & designing of water harvesting (crediting) measures.

1. Planning & designing of contour terracing.
2. Planning & designing of drains.
3. Planning & designing of water structures.

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4. Planning & designing of wells, ditches, bore holes, tanks etc.
5. Planning & designing of percolation drains and storage tanks.
6. Planning & designing of subsurface drains.

Cropping planning. Interpretation of meteorological, soil and cropping data.

1. Estimation of crop water requirement.
2. Preparation crop-water balance sheet.
3. Preparation of crop cultivation manual.
4. Estimation of yield, market pricing and sales.
5. Estimation of income and profitability.

Planning & Designing of water management (Drip Irrigation) system.

1. Planning & designing of efficient drip irrigation and watering system to crops.
2. Planning & designing of efficient power unit. (Pumping cost).
3. Planning & designing of supplementary irrigation system.

Preparation of detailed Project report with economics analysis.

1. After finalization of planning & designing, proper estimation of each components.
2. Preparation of feasible report with economics.

Execution and commissioning.

After justification and approval, execution of entire project has been undertaken.

Periodically monitoring of system & findings.

1. After implementation of entire scheme, monitoring of system has been completed periodically and necessary repairing and maintenance, measurement of water discharges have been undertaken and recorded for future reference and planning.
2. Impact on environment and wildlife were studied carefully.
3. Return on investment was monitored on a yearly basis.
4. Review of overall data with conclusion.

METHODOLOGY

GPS contour survey was conducted of entire area to know the actual topography of site scaled to 1 m interval. Base on contours, slope and water flow various methods and measures of restoring surface runoff, i.e. contour terracing, contour cross drains, digging pits, drilling holes, loosening soil, cutting and fillings, were planned, designed and adapted in all directions the farm, as shown in Figure 1 and explained in Table 1.

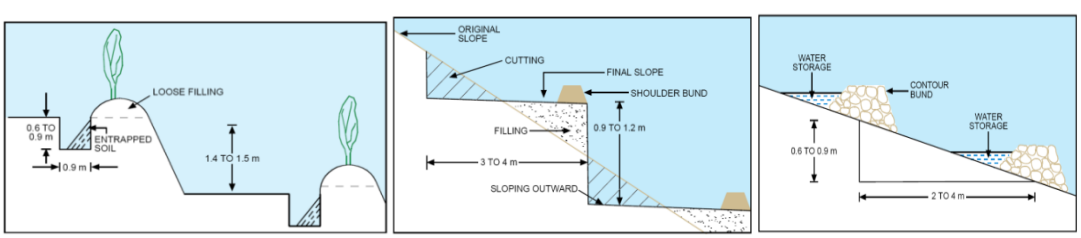

Figure 1. Various methods adapted — rain water harvesting

Table 1. Following measures have been adapted in restoring rain water.

Sr.	Method adapted	Purpose and benefits
1	Contour Terracing	To flatten the sloping land along the contour for planting and easy movement of machinery.
2	Contour & Cross drains	To collect/convey rain water to main drain and storage. Also helps to prevent soil erosion.
3	Digging Pits	To store water and improve water table in ground.
4	Drilling shallow holes	To allow deep percolation & harvesting of rain.
5	Loosening soil. (Improving porosity)	To allow storage on water in soil, increase infiltration and thereby improve water table.

Climatic data of last five years has been collected from nearest Government Meteorological station and average data is shown in Table 2 for the reference purpose. It helps to plan overall cropping pattern at minimal risk with an estimation of water accumulations from rain fall. From the climatic data, it is very clear that there is a direct deficit of 1430 mm (Evapotranspiration 2036 mm –rainfall 606 mm) to meet the crop water demand in a year. Since the rain fall is spread over four months in a year, so agricultural is normally done only for 4-6 months till availability of moisture in soil and rest of the month undergoes dry and nonproductive.

Only 2 to 3” layer so called soil is available at Jain hills with pH range 6.5 to 7.8, insignificant organic matter, NPK and water holding capacity. Under such conditions proper & precise planning, designing and implementation of various agro-engineering techniques were optimized and implemented to maximize the benefits and utility.

Table 2. Meteorological data of Jalgaon

Sr.	Month	Min Temp (^{0} C)	Max Temp (^{0} C)	Rain (mm)	ET(mm)
1.	Jan	15	30	Nil	133
2.	Feb	18	35	Nil	145
3.	Mar	23	37	Nil	195
4.	Apr	28	41	Nil	230
5.	May	35	45	Nil	260
6.	Jun	32	42	70	195
7.	July	30	38	170	142
8.	Aug	28	35	190	146
9.	Sept	26	35	150	157
10.	Oct	23	34	26	173
11.	Nov	19	32	Nil	137
12.	Dec	16	30	Nil	123
13	Annual			606	2036

Considering climatic data and soil, proper cropping pattern has been planned and prepared a crop water balance sheet with various options and alternatives lowering risk and maximising benefits from it. Advanced Micro Irrigation System and water management technique have been adapted to use every drop of water for productivity of agriculture as shown in Figures 2 and 3.

Figure 2. Gully Plugging & plantation.

Figure 3. Drip Irrigation & terracing plantation

A comparative case study is represented in mathematical model in a commercial trend of balance sheet (debit and credit) of water before and after adaption of various techniques in Table 3 & 4.

Table 3. Water Balance Sheet Before adapting Rain Water Harvesting

Commerce accounting method has been used to represent water balance sheet for 1 ha model per year for easy understanding. (It is a new technique formulated by the author on certain assumption).

Sr	Account head	Credit (million litres)	Debit (million litres)	Balance (million litres)	Assumptions / Remarks
1	Accumulation of Rain l in 1 ha.	6.00		6.00	Credited by nature. Opening balance. Rainfall (600 mm x 10000 sq.mt = 6 million litres).
2.	Direct loss - Surface Run off - due to slope		3.6	2.40	It is due to slope and estimated to 60% of rainfall and not utilized.
3.	Consumptive use in conventional crops. It is take from June Nov (6 months).		3.8	(-)1.4	It is estimated. 950 mm (ETP) x1 ha = 9.5 million litre. Practically,100 % not applied and only 40 % applied.3.8 million litre) (-) 1.4 million litre deficit
4	Total	6.0	7.4	(-)1.4	Shortfall 36 % of irrigation. Means direct reduction in production 36 %.
Note : There is a short fall of 1.4 million litre of water for irrigation. On contrary there is direct loss due to surface run off 2.40 million litres. This shortfall can be compensated by adapting various techniques of water harvesting, proper cropping pattern & drip irrigation system and thereby production can be increased by 36 %. Only 6-7 months can be utilized for cultivations and rest of months remain uncultivated. This is also another kind of losses.					

Table 4. Water Balance Sheet After adapting Rain Water Harvesting

Commerce accounting method has been used to represent water balance sheet for 1 ha model per year for easy understanding. (It is a new technique formulated by the author on certain assumption).

Sr.	Account head	Credit (million litres)	Debit (million litres)	Balance (million litres)	Assumptions / Remarks
1	Accumulation of Rain l in 1 ha.	6.00		6.00	Credited by nature. Opening balance. Rainfall (600 mm x 10000 sq.mt = 6 million litres).
2.	No Direct loss - Surface Run off.		0	6.00	It is eliminated 100 % roughly by adapting various methods.
3.	Consumptive use in advanced crop planning for 12 months.		6.10	(-) 0.1	It is estimated. 2036 mm (ETP) x1 ha x 0.30 =6.10 million litre. Under drip irrigation, mulching & precise irrigation scheduling. (-) 0.10 million litre deficit in year.
4	Total	6.0	6.10	(-) 0.1	Shortfall 1% of irrigation.
Note: There is insignificant short fall 0.1 million litre of water for irrigation in year. It can be compensated by micro planning and scheduling of water management. Here, year round productions can be taken. Besides this there are many benefits like increasing ground water tables, soil moisture and micro climate.					

In addition to above water balance sheet, financial analysis is presented in Table 5 to get confirmation and confidence of this technique and is based on true crops harvested of Mango with intercrops like Onion, vegetable as seen in Figure 4.

Table 5. Financial (Economics) Analysis for 1 ha representative area
(if 100 % loan taken from Bank).
(Conversion rate used: 1 USD = 44 Indian Rupees)

Sr.		Head	Values (USD)
1		Investment details	(Per ha basis)
	a.	Investment for water harvesting like terracing, drains, pits, loosing soils, construction of earthen structure.	7,000.00
	b.	Installation of Drip irrigation System	1,700.00
	c.	Cost of cultivation horticulture(Mango, forestry & vegetables)	2,000.00
	d.	Total investment (USD)	10,700.00
2		Repayment per annum	
	a.	Interest @ 15 % per year (if 100 % loan taken from Bank)	1,605.00
	b.	Equated principal in 6 years (per year)	1,704.00

	c.	Depreciation of drip system @ 10 % per year.	170.00
	d.	Electrical charges @ 50 USD per year (subsidized rate)	50.00
	e.	Operation & Maintenance expenses @ 5 % per year	535.00
	f.	Repayment per year (USD)	4,064.00
3		Returns (Income)	
	a.	Yield of Mango per ha (ton)	7.00
	b.	Yield (Intercrops) Onion / Vegetable per ha (ton)	3.00
	c.	Selling price of Mango (USD per ton)	600.00
	d.	Selling price of Vegetable(USD per ton)	80.00
	e.	Income from Mango (USD)	4,200.00
	f.	Income from Vegetable (USD)	240.00
	g.	Total Income (USD)	4,440.00
4		Net Profit (Income) (USD)	376.00
5		Benefit Cost Ratio	1.10
6		Payback Period (4 year gestation period for Mango)	4 + 3= 7 years

Figure 4. True Mango + Onion +Vegetable (intercrop) under Drip Irrigation.

<u>Other auxiliary advantages/benefits achieved.</u>

1. Own water source created to meet the need of agriculture and industrial use.
2. Great rain water savings achieved. No wastage of rain water.
3. Advantage of topography taken to run the system partly by gravity, so there is a great achievement in savings of power cost.
4. Barren land made into cultivable land so substantial income generated from various horticulture & intercrops.
5. Improved cropping pattern & management help to reduce overall cost of cultivation /inputs.
6. Protecting soil from erosion, degradations, salinity and water logging.
7. Enhancement in environment, green belt, controlled of pollution & Carbon credits.
8. Protection of wildlife–Deer, Peacocks, wild birds, Monkey, Fox, Snakes etc.
9. Generation of direct employment - unskilled & skilled, technicians, engineers etc

as well as indirect employment such as suppliers, manufacturer, shops, brokers, machinery stores, transports services, etc. at village level which helps to prevent migration to city and thereby improvement in standard of living of people at rural level.

Figure 5. Final shape of the Jain Hill after WH measures before plantation

Figure 6. Final Result — Water Storage and Crops.

CONCLUSION

Figures 5 and 6 are self-explanatory, proven resultant of turning barren land into productive. It is supported in economics, overall benefit cost ratio works out to 1.10 with payback period of 7 years (considering gestation period 4 years for crops) and net additional profit of USD 376.00 per ha basis apart from other unforeseen benefits.

In a nutshell, it is a true success story of water harvesting, contributing in GDP of nation at micro level.

This is a proven model for many African countries, suffering from water, food and employment security problems.

That's why father of nation Mahatma Gandhi has quoted, 'Development and progress of nation will only happen if we start revolution from rural base'. Everybody must accept this truth and contribute in water harvesting and water management technique for progress of nation.

CALLOWAY CANAL TO LERDO CANAL INTERTIE

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ABSTRACT

The Calloway Canal to Lerdo Canal Intertie (Project) was constructed by North Kern Water Storage District (North Kern) as part of a regional water supply enhancement strategy for an area in northern Kern County, CA. The project involved replacing an existing gravity connection with an enlarged bi-directional water conveyance connection that includes 400 cfs of pumped capacity. Pumping allows for the delivery of CVP-Friant water from the Friant-Kern Canal into North Kern's Lerdo Canal for delivery to water spreading facilities, which can only be served from the Lerdo Canal. These water spreading facilities are located in both North Kern and Cawelo Water District and represent the most significant direct recharge assets in the Poso Creek Integrated Regional Water Management Plan Region. As a result of linking CVP-Friant water with these spreading assets, significant quantities of water can be absorbed on an as-available basis and reregulated or banked.

INTRODUCTION

The Calloway Canal to Lerdo Canal Intertie is a bi-directional water conveyance pipeline linking the North Kern Calloway Canal to the Lerdo Canal. This conveyance facility is in an ideal location for enhancing conjunctive use in the Poso Creek Integrated Regional Water Management (IRWM) Region. The facility will be used to divert and deliver wet-year Central Valley Project water for groundwater recharge and support groundwater levels.

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GEI planned, designed and provided construction management services for this Project, which consisted of a one-mile long, 96-inch reinforced concrete pressure pipe; a 400-cfs, 3800HP pumping plant complete with concrete work, earthwork, metalwork, electrical, instrumentation and trash racks; three farm turnouts; a crossing of the Friant-Kern Canal; and tie-in connections to the Calloway Canal and Lerdo Canal. The Project, completed in 2011 for a total cost of just over $10,900,000, was partially funded by the Bureau of Reclamation through the 2009 ARRA funded WaterSMART program for which GEI prepared the grant application. The Project team completed all project requirements on a compressed schedule, accomplishing the goals set forth by the funding agency.

DISTRICT BACKGROUND

North Kern is an agricultural water district located north of the Kern River in the San Joaquin Valley portion of Kern County, California. Comprising some 60,000 gross acres, the District lies between the City of Bakersfield on the south and the City of Delano on the north, and between Highway 99 on the east and the cities of Wasco and Shafter on the west. North Kern's primary source of surface water is the Kern River, whose waters have been utilized under a schedule of long-standing diversion rights. While North Kern is not a long-term CVP contractor, it is noteworthy that Reclamation's Friant-Kern Canal courses from north to south through the "middle" of North Kern, and the District has purchased and diverted "surplus" CVP-Friant water when available. North Kern is shown on Figure 1 along with locations of the district facilities in relation to the other members of the Poso Creek IRWMP.

North Kern's principal source of surface water is the Kern River. North Kern's supplies from this source are highly variable and have ranged from less than 10,000 acre-feet in a "dry" year to nearly 400,000 acre-feet in a very "wet" year. However, over the long term, annual diversions from the Kern River by North Kern have averaged about 178,000 acre-feet. Annual hydrographic reports for the Kern River are the source of the data for this calculation.

Surface water is delivered through approximately 130 miles of unlined canals (heading at two diversion points on the Kern River), 20 miles of pipeline, and 20 miles of lined canal. The District's principal supply artery, and most upstream point of diversion on the Kern River, is the Beardsley-Lerdo system, with a capacity of 850 cfs. This system is entirely gravity flow and consists of the diversion structure on the Kern River, 9.5 miles of concrete-lined canal (the Beardsley Canal) between the headworks and the District's southern boundary, and an unlined canal section (the Lerdo Canal) that continues along North Kern's eastern side. The second point of diversion, 4.5 miles downstream of the first, is the Calloway headworks that services the relatively large, unlined section of the Calloway Canal, with a capacity of 1,000 cfs. This facility is also entirely gravity flow and extends for 10.4 miles before entering North Kern at Seventh Standard Road. Kern River water that exceeds the immediate irrigation requirements is introduced directly underground through the use of about 1,500 acres of recharge basins at five sites, three of which can only be served from the Lerdo Canal.

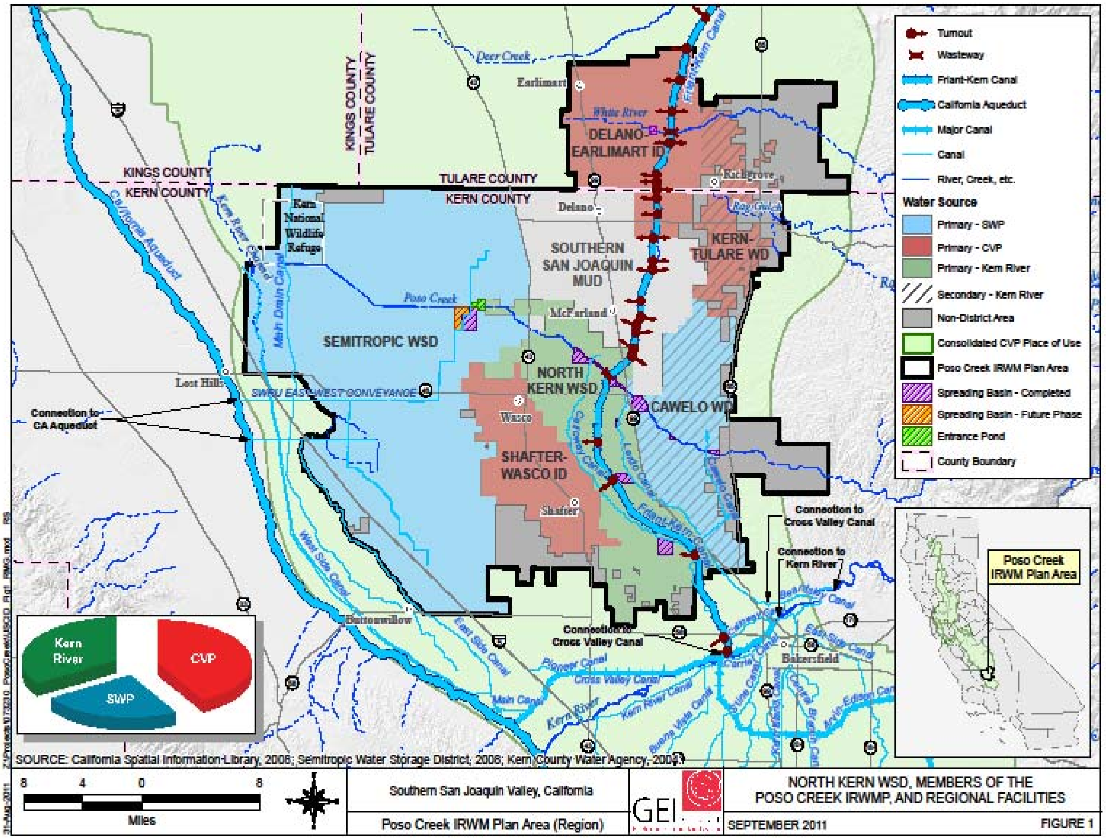


Figure 1. North Kern WSD, members of the Poso Creek IRWMP, and regional facilities.

These facilities, the channel of Poso Creek, as well as the unlined conveyance canals within the District, have combined to directly recharge up to 24,000 acre-feet in one month and over 250,000 acre-feet in one year (1998). In years of deficient water supply, continuity of delivery to the surface water service area is maintained by the operation of over 70 deep wells owned and operated by North Kern. These wells are not used in “wet” years and have produced up to 100,000 acre-feet in a very “dry” year.

PURPOSE AND NEED FOR REGIONAL WATER MANAGEMENT

In 2005, North Kern joined with several of its neighboring water agencies to develop an Integrated Regional Water Management Plan (IRWM Plan) for the region. In addition to North Kern, the agencies that developed and adopted the resulting Plan included Cawelo Water District, Shafter-Wasco Irrigation District, Semitropic Water Storage District, Kern-Tulare Water District, Delano-Earlimart Irrigation District, and the North West Kern Resource Conservation District. Collectively, these agencies are referred to as the Poso Creek Regional Water Management Group, and represent about 350,000 irrigated acres and a gross area on the order of 500,000 acres.

In July 2007, the group completed and adopted the IRWM Plan. This Plan identified and characterized about 30 projects which address water supply reliability for the Region. The Project was included and was ranked as a “Tier 1” project, which identifies projects that are recommended by the group for near-term implementation. The Plan includes the following statement with regard to this particular project:

> “The Project is an important element in implementation of the IRWM Plan and in meeting with the Plan’s central objective of enhancing local and regional water supply reliability and in addressing the Plan’s objectives of managing groundwater and surface water resources within the region.”

The Project was developed collaboratively with neighboring CVP and SWP districts as part of the Poso Creek IRWM Plan and as part of the Water 2025 System Optimization Review for the Poso Creek IRWM Plan Area. In this regard, it is noted that Cawelo Water District was a cost-share partner with North Kern. As recognized in the Plan, all projects that result in greater absorption of surface water supplies available to the Region (including the Project) benefit all users which rely in whole or in part on the underlying common groundwater resource. In this regard, recall that surface water which is brought into the Region is the primary source of recharge to the groundwater basin. Further, history has shown that it is likely, if not a certainty, that the Project will be used for banking and exchange arrangements that have not yet been conceptualized.

This Project supports the priority water management strategy to enhance the region’s water supply and reliability through increased conjunctive management of surface water and groundwater. This Project, identified as No. 12 in the Poso Creek IRWM Plan, is also one of the regional projects that have been implemented since formation of the Poso Creek IRWM Plan. The locations of the priority facilities identified to enhance regional conjunctive water management are shown in Figure 2.

PROJECT BENEFITS

Available surface water supplies and groundwater are used conjunctively in the Region. The surface water supplies are the principal source of recharge to the underlying groundwater system, and include local Kern River and Poso Creek water, as well as water imported from the Central Valley Project and State Water Project.

Loss of water supply reliability (owing to both regulatory and judicial actions) was the fundamental issue or concern which was identified in the Poso Creek IRWM Plan. The Project was identified in the plan specifically to address this concern by increasing the Region’s absorptive capability when surface water supplies are available. In particular, the Project connects one source of available supplies (CVP-Friant) to underutilized spreading capability in both North Kern and Cawelo. As a result, more water will be brought into the Region (as compared to the no-Project condition) to recharge the underlying groundwater basin, which provides for all water needs in the Region to the extent that surface water supplies are deficient. The underlying groundwater basin is important in any year, but is critical during periods of drought, when the use of groundwater escalates.

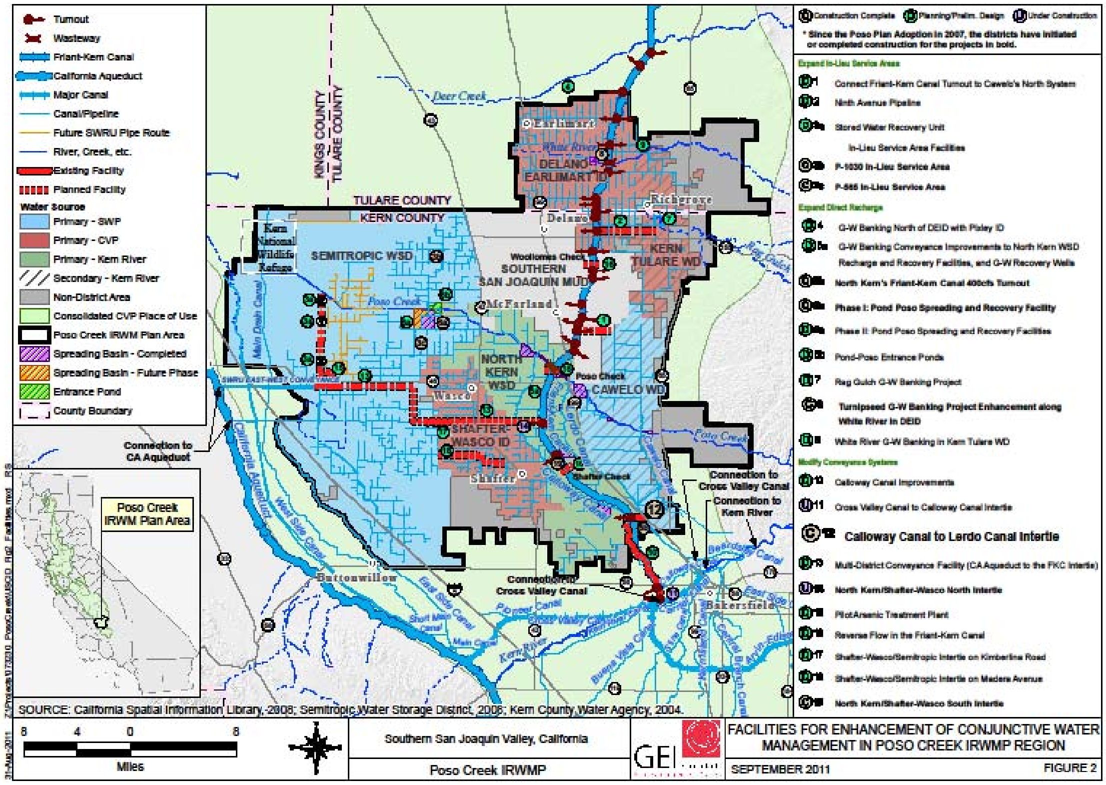


Figure 2. Facilities for Enhancement of Conjunctive Water Management in Poso Creek IRWMP Region.

With regard to quantification of actual Project benefits, it should be noted that this will not be practicable immediately; rather, it could take several years, depending on hydrology, to obtain a meaningful measure of Project benefits. Project performance will be based on comparison of the pre- and post-project deliveries through the bi-directional intertie, which will be the result of actual flow measurements. Comparison will involve consideration of monthly and annual volumes. The post-project performance will be measured by documenting the volume of water that is diverted from the Friant-Kern Canal and pumped into the Lerdo Canal. Records of the volume of water delivered to the Lerdo Canal through use of this Intertie will be a direct measure of the project benefits, as this water would have otherwise been lost.

Since construction of the Project has just been completed in 2011, the operational information with which to "measure" the amount of water conserved, marketed, or better managed will happen over time. Based on monthly operations studies over a long-term period of hydrology, it is estimated that the Project will allow for banking from 13,000 to 17,100 acre-feet per year of CVP-Friant water on average over the long term. Individual years are projected to range from zero to over 60,000 acre-feet.

PROJECT COMPLETION DESCRIPTION

Since North Kern received an ARRA funded grant for a portion of the Project costs, the Project was completed following a schedule to meet a targeted completion date of January 31, 2011. Several tasks were defined to accomplish the Project Work and organized to track with Budget and Schedule items in a manner acceptable to Reclamation's WaterSMART program.

The tasks, and work completed for each task, are described as follows:

Task 1: Administration

Involved coordination of all Project activities, including budget, schedule, communication, and grant and cost-share administration (preparation of invoices and maintenance of financial records). Deliverables included preparation of invoices and other deliverables, as required.

Task 2: Reporting

Activities included preparation of quarterly (financial and activity) reports to Reclamation; a summary of project expenditures and a corresponding description of project activities with each reimbursement request to Reclamation; Monthly Construction Progress Reports; and a Final Report.

Task 3: Design

Design activities included survey and geotechnical work, and preparation of design documents, including final plans and specifications for two construction contracts; one for the construction of the Friant Kern Canal Crossing and the other for the Calloway Canal to Lerdo Canal Intertie. Documents were also prepared for procurement of pipe for the pipeline crossing of the Friant-Kern Canal in order to expedite construction of this feature during a narrow construction window in the winter of 2009-2010.

Task 4: Environmental Documentation

Support was provided to Reclamation regarding preparation of an Environmental Assessment (EA) for the Project. This included preparing a substantially complete draft of the EA; and coordination of both biological and cultural resource assessments, with the latter including an historical assessment of the 8-1 Canal. A field survey by a qualified biologist was repeated shortly before commencement of construction to ensure the construction areas remained unoccupied by sensitive species. Confirmation of a completed pre-activity biological survey, as well as survey results, was provided to Reclamation.

Task 5: Permitting

The necessary submittals were made to Reclamation to support issuance of a permit to construct the new pipeline (siphon) crossing of the Friant-Kern Canal; these included applicable plans and specifications. In addition, plans were submitted to Reclamation (and approved) for abandonment of the existing pipeline crossing of the Friant-Kern Canal. No additional permitting was required, as the remainder of the Project work involved District-owned rights-of-way.

Task 6: Construction

The Project consisted of two construction contracts; one contract (Specifications No. NK-600) for construction of the Friant-Kern Canal crossing; and a second contract (Specifications No. NK-603) for construction of a 3,800 horsepower pumping plant, 96-inch diameter (RCP) pipeline (about one mile in length), flow control weir, inlet/outlet structure (between canal and pipeline), and canal lining. The Project replaced a portion of the 8-1 Lateral Canal with a pipeline to facilitate pumping water from the Calloway Canal or Friant-Kern Canal into the Lerdo Canal. The 8-1 Lateral siphons under the Friant-Kern Canal en route from the Lerdo Canal to the Calloway Canal. At the Friant-Kern Canal, the new pumping plant lifts the water to the Lerdo Canal through the new pipeline extending from the west side of the Friant-Kern Canal to the Lerdo Canal (a distance of about one mile). The pumping plant and pipeline have a design capacity of 400 cfs. A series of Construction Progress Reports were prepared for North Kern that provided a more detailed description of the work completed, including pictures of Project works during construction.

Task 7: Construction Management

Specific Construction Management activities included advertisement for bids; preparation of abstracts of bids received; issuance of Notices to Proceed; pre-construction meetings; correspondence with the contractors; submittal review; start-up and testing verification; field inspection; witnessing shop testing of pumps and motors; in-plant inspection of pipe manufacture; progress payments; Contract Change Orders; filing Notices of Completion; and preparation of “As-Builts.”

PROJECT CONSTRUCTION

Site Plan

The main components of project construction included installation of a 96-inch diameter steel pipeline crossing of the Friant-Kern canal, a 3,800 horsepower pumping plant, and 96-inch diameter (RCP) pipeline (about one mile in length). A schematic of the Lateral 8-1 and the Pumping Plant are shown in Figure 3.

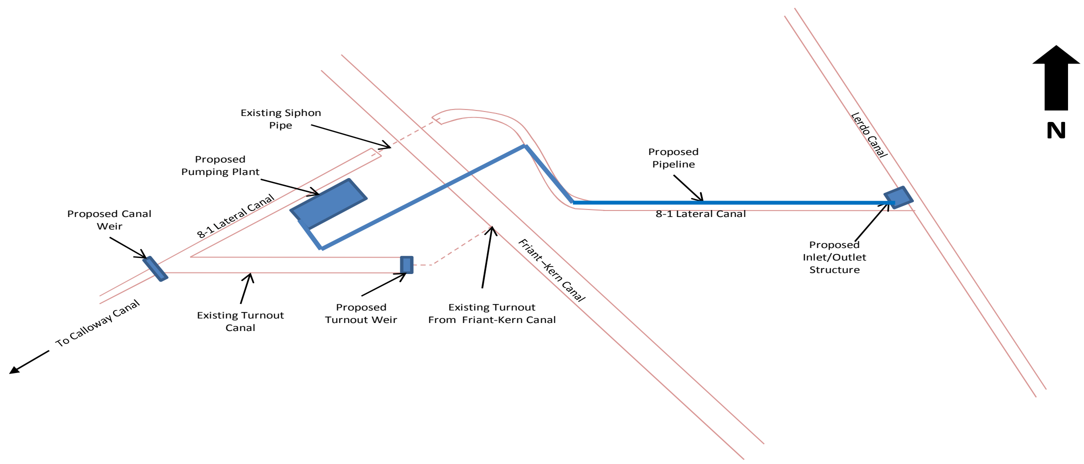


Figure 3. Schematic of 8-1 Canal and the Pumping Plant

CONCLUSION

This Project was constructed in sequence with other regional conveyance improvements for the main purpose of supporting the priority water management strategy to enhance the Region's water supply and reliability through increased conjunctive management of surface water and groundwater. Based on monthly operations studies over a long-term period of hydrology, it is estimated that the Project will allow for banking from 13,000 to 17,100 acre-feet per year of CVP-Friant water on average over the long term. Individual years are projected to range from zero to over 60,000 acre-feet.

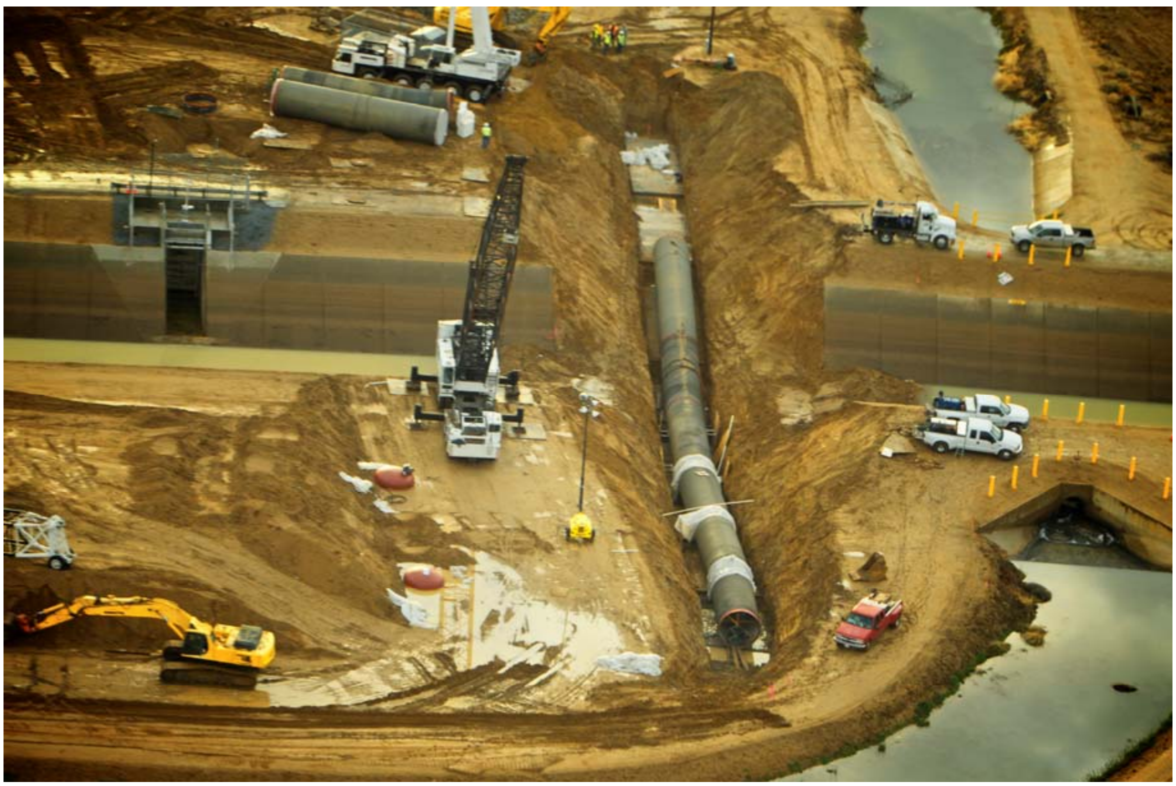
The Project is intended to serve several purposes; however, one of the most significant is the greatly enhanced ability to divert and deliver wet-year Central Valley Project water, with the over-arching goal of recharging the underlying groundwater basin, and thereby supporting groundwater levels. Under "normal" circumstances, this year (2011) would have been a good year to realize significant diversions of CVP water; however, the temporary imposition of a storage restriction on Isabella reservoir by USACE is forcing North Kern to use all of its absorptive capability to regulate its primary source of surface water (Kern River) concurrent with the availability of CVP water during this "wet" year.

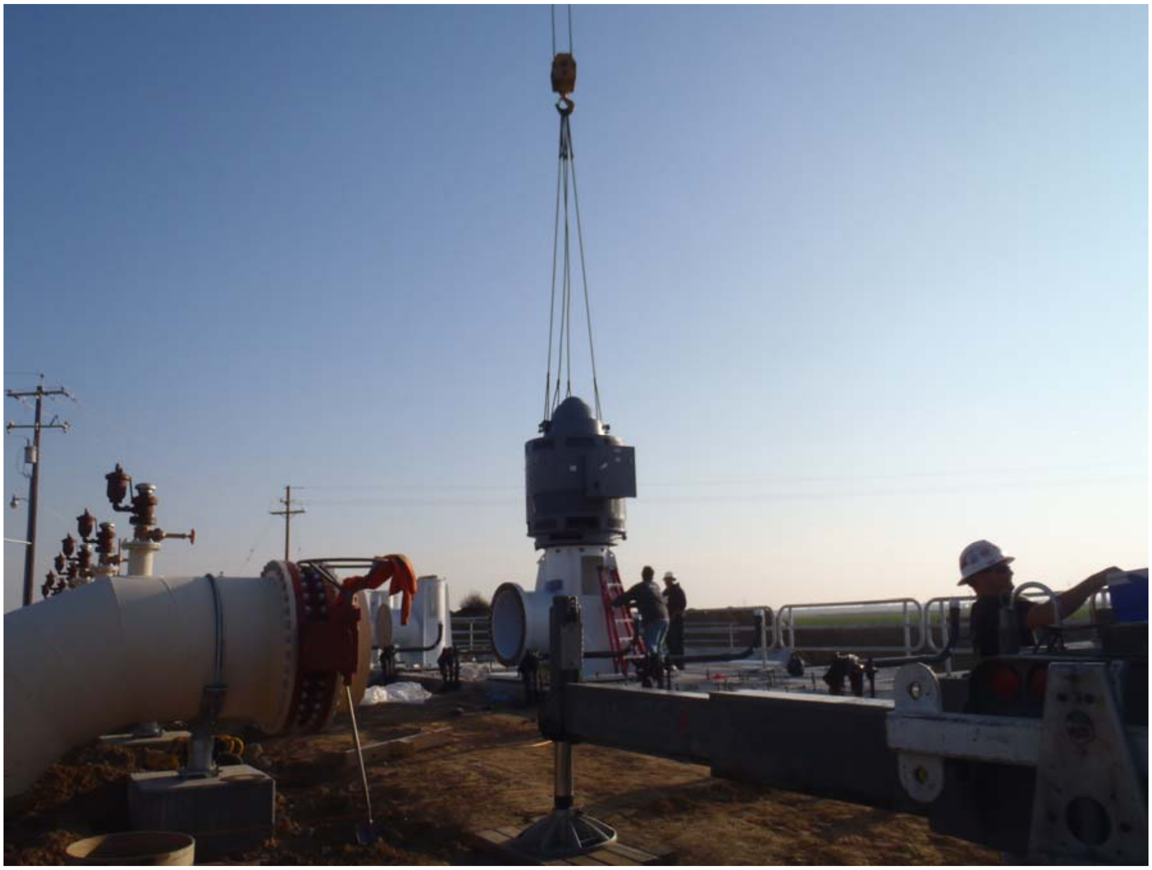
ACKNOWLEDGEMENTS

A special thanks to North Kern WSD, Cawelo Water District, and all of the districts in the Poso Creek IRWMP who supported the development of this project from concept through construction.

Photos

Select photos of the construction follow for the installation of a 96-inch diameter steel pipeline crossing of the Friant-Kern canal, a 3,800 horsepower pumping plant, and 96-inch diameter (RCP) pipeline (about one mile in length).





CHARACTERISTICS OF IRRIGATION PUMP PERFORMANCE IN MAJOR IRRIGATED AREAS OF CALIFORNIA

Sierra A. Orvis[1]
Charles M. Burt[2]
Luis Perez Urrestarazu[3]

ABSTRACT

Well pump tests (12,876) in three Central California groundwater basins were characterized and described according to their spatial distribution. The average overall pumping plant efficiency (wire-water, not including column losses and velocity head) was about 56%. Characteristics such as drawdown, total dynamic heads, kW, and flow rate vary greatly between pumps within and between sub-basins. This is the first well pump characterization of its type in California, although irrigation pump tests have been conducted for over 70 years in California. This paper provides a summary of the spatial variation of well pump performance and characteristics.

Background

In work sponsored by the Public Interest Energy Research (PIER) program of the California Energy Commission, ITRC analyzed information recovered from over 15,000 electric irrigation pump tests in Central California. The pump tests were located throughout the Sacramento, Salinas, and San Joaquin Valley groundwater basins of California. These large groundwater basins are each also divided into a number of subbasins. A map depicting this is shown as Figure 1 (gray lines outside of basins represent county lines; gray lines inside basins represent subbasins).

Data was analyzed by basin and subbasin for well pumps and non-well pumps. For each pump type, averages were calculated based on:

- The whole basin
- Overall pumping plant efficiency (OPPE)
- kWh/AF
- Subbasins

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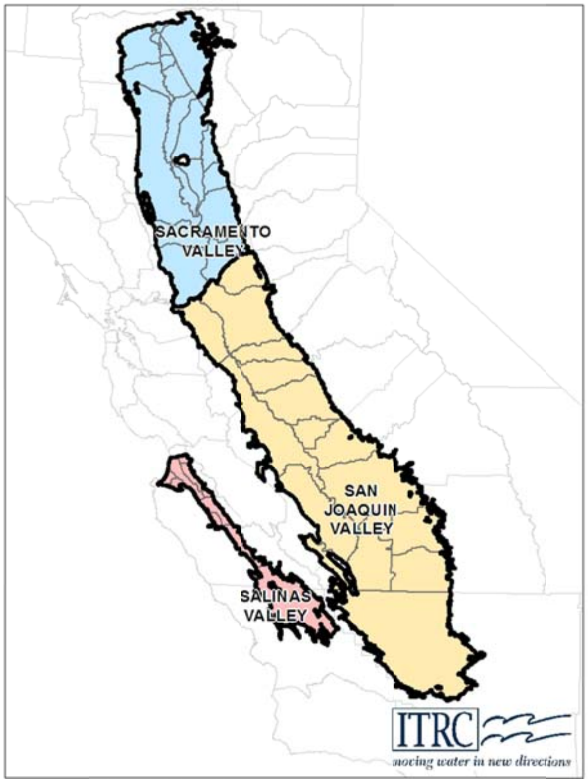
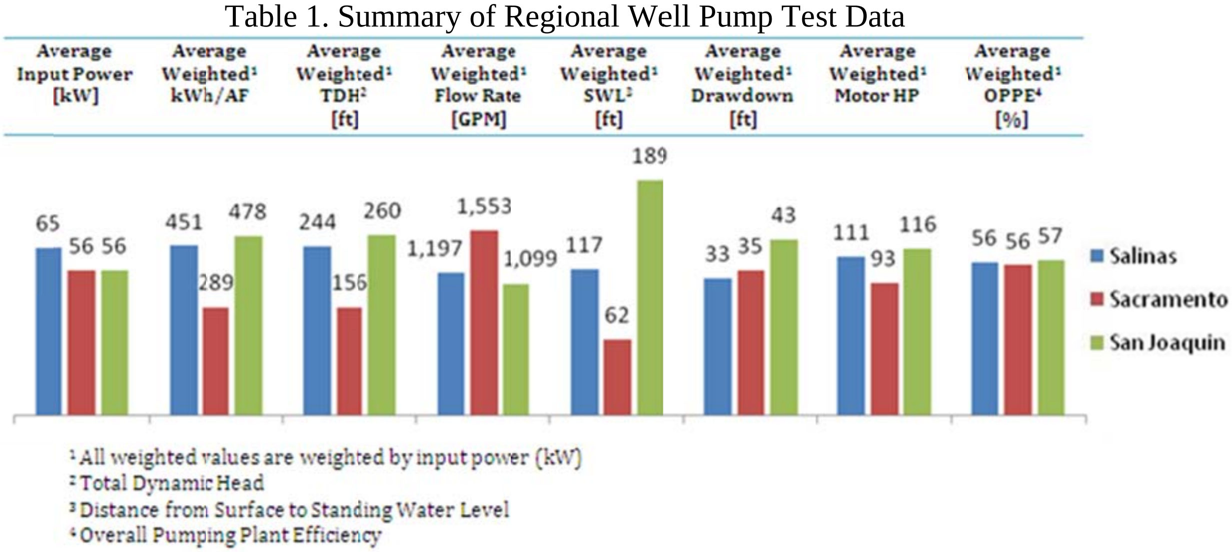


Figure 1. Groundwater Basins in California

Well Pump Subbasin Comparisons

Throughout the three groundwater basins, data from 12,876 well pump tests was analyzed. Table 1 summarizes the averages of a variety of factors from well pump tests in each of the three groundwater basins.

Table 1. Summary of Regional Well Pump Test Data



When comparing the data from the three basins, some general observations regarding the well pump data can be made:

1. All three basins have very similar average OPPEs (~56%).
2. The Salinas basin's well pump tests had a slightly higher average input power than the well pump tests in the other basins.
3. The Sacramento basin's well pump tests had a higher average flow rate and lower average kWh/AF, total dynamic head, motor HP, and depth to standing water level than the well pump tests in the other basins.
4. The San Joaquin basin's well pump tests had a greater average depth to standing water level and average drawdown than the well pump tests in the other basins.

Regional Comparison by Overall Pumping Plant Efficiency (OPPE)

The data for each basin was compared with overall pumping plant efficiency (%) to the data displayed in Figures 2-9. The values are grouped into 10% ranges, with the data value displayed on the chart at the midpoint of the range (for example, the average value for the 21-30% range is placed at the 25% point). The grayed areas show the ranges where a majority of the values lie.

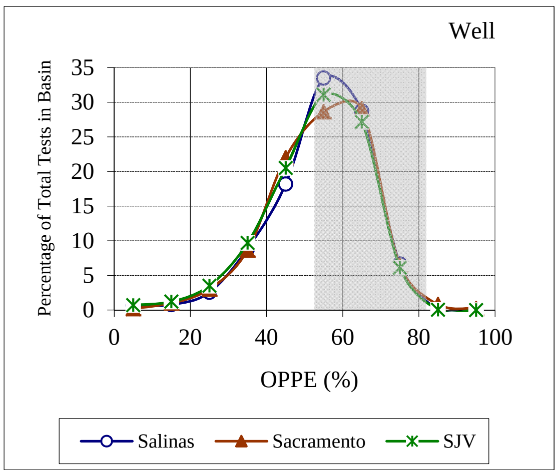


Figure 2. Test Distribution

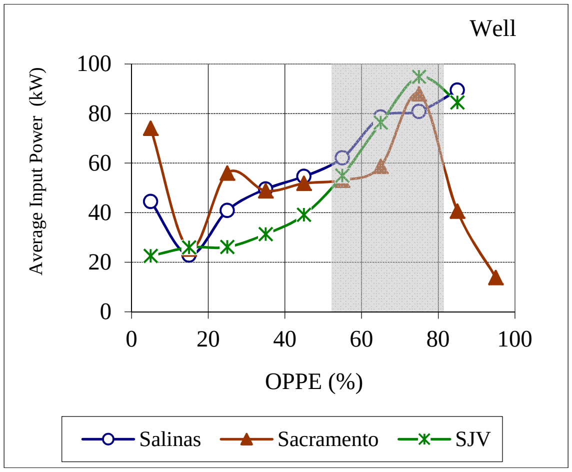


Figure 3. Average Input Power [kW]

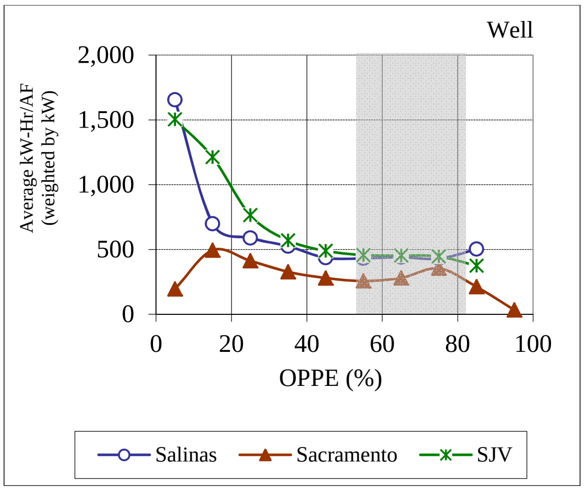


Figure 4. Average kWh/AF (Weighted by Input Power)

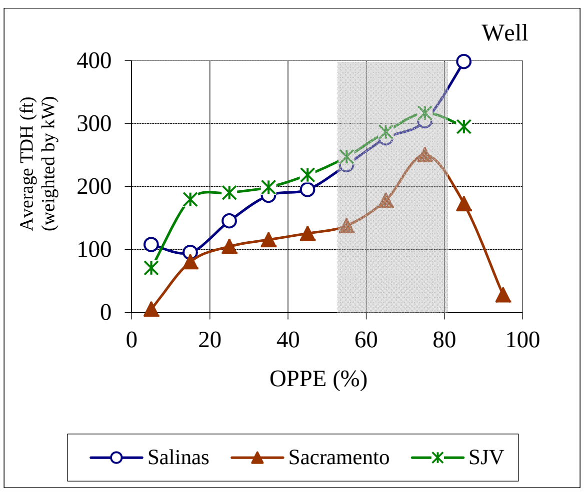


Figure 5. Average Total Dynamic Head (TDH) [ft] (Weighted by Input Power)

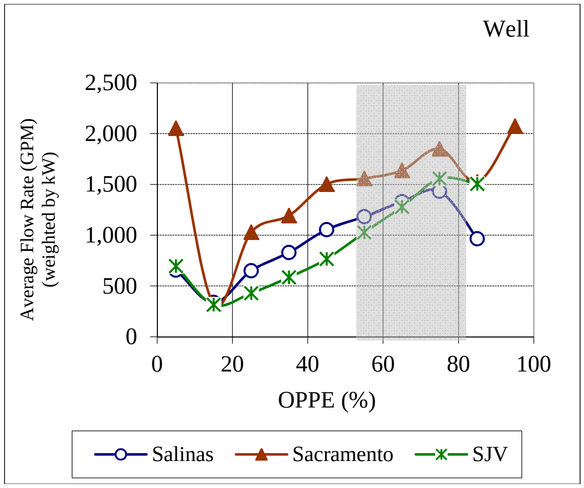


Figure 6. Average Flow Rate [GPM] (Weighted by Input Power)

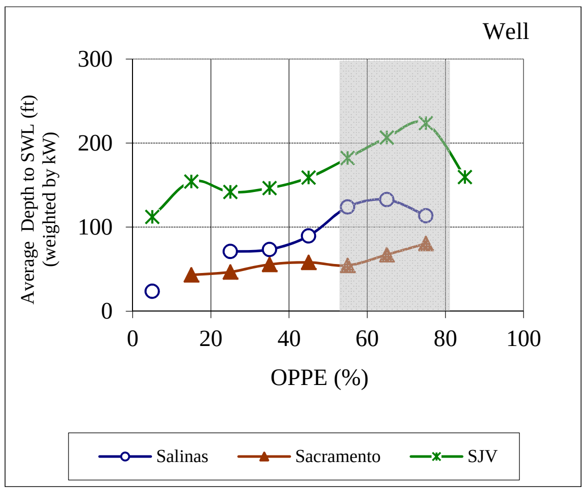


Figure 7. Average Depth to Standing Water Level (SWL) [ft] (Weighted by Input Power)

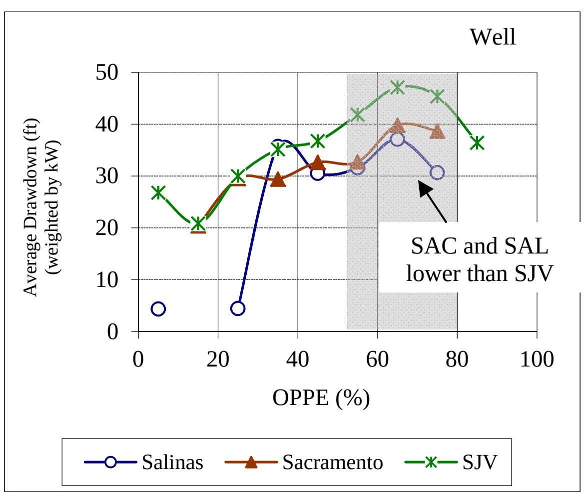


Figure 8. Average Drawdown [ft] (Weighted by Input Power)

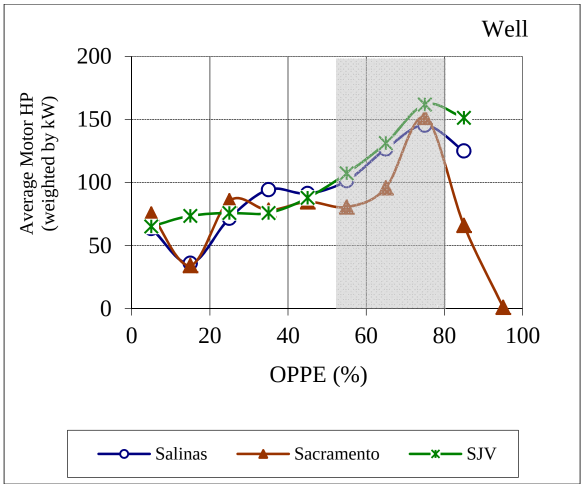


Figure 9. Average Motor HP (Weighted by Input Power)

When comparing the data from the three basins to the overall pumping plant efficiency, some general observations regarding the well pump data can be made:

1. A majority of the well pump tests fall between the 40-70% overall pumping plant efficiency ranges.
2. Across nearly all of the overall pumping plant efficiency ranges, the Sacramento basin's well pump tests have a higher flow rate, and a lower kWh/AF and total dynamic head than the well pump tests in the other basins.
3. The San Joaquin basin's well pump tests had higher average drawdown values than the well pump tests in the other basins.
4. The average depth to the standing water has a lot of variation between basins.

<u>Regional Comparison by Energy Consumption per Volume Pumped</u>

The data for each basin was compared with kWh/AF to the data shown in Figures 10-17. Each basin had a single data point placed at 1000 kWh/AF that represents the y-axis average value for all data points greater than 1,000 kWh/AF. The values are grouped into ranges of 100 kWh/AF with the data value displayed at the midpoint of the range (e.g., the average value for the 201-300 kWh/AF range is placed at the 250 kWh/AF point). The grayed areas show the ranges where a majority of the values lie.

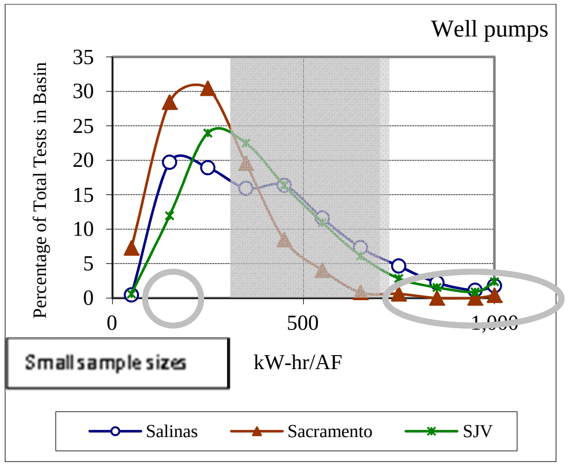


Figure 10. Test Distribution

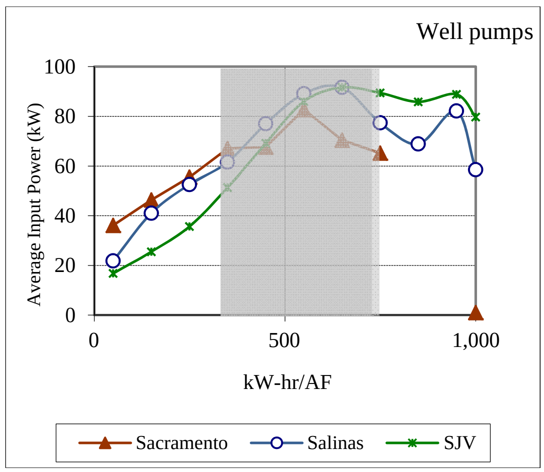


Figure 11. Average Input Power [kW]

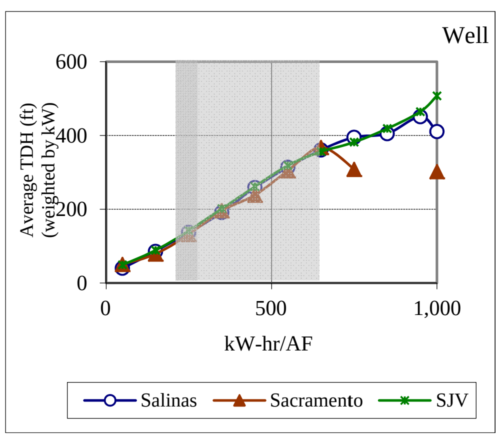


Figure 12. Average Total Dynamic Head (TDH) [ft] (Weighted by Input Power)

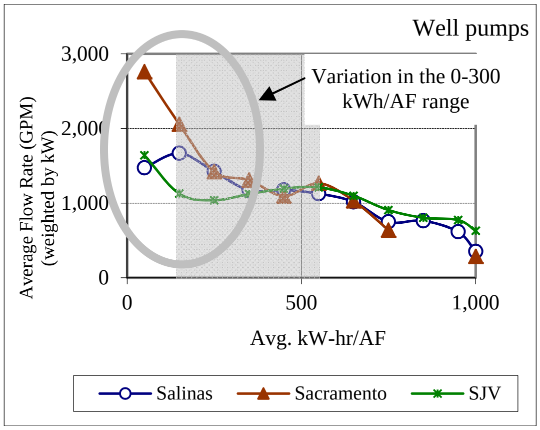


Figure 13. Average Flow Rate [ft] (Weighted by Input Power)

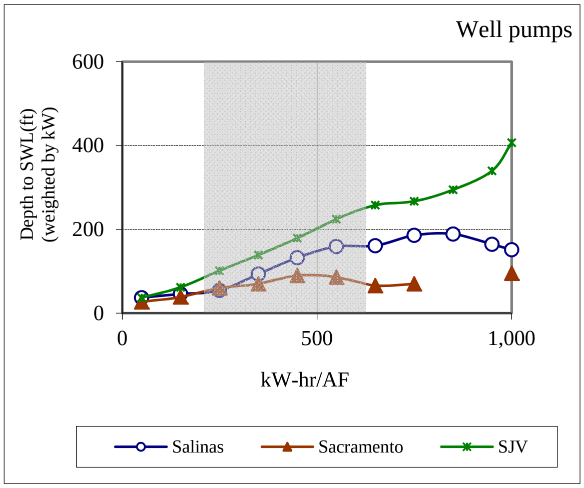


Figure 14. Average Depth to Standing Water Level (SWL) [ft] (Weighted by Input Power)

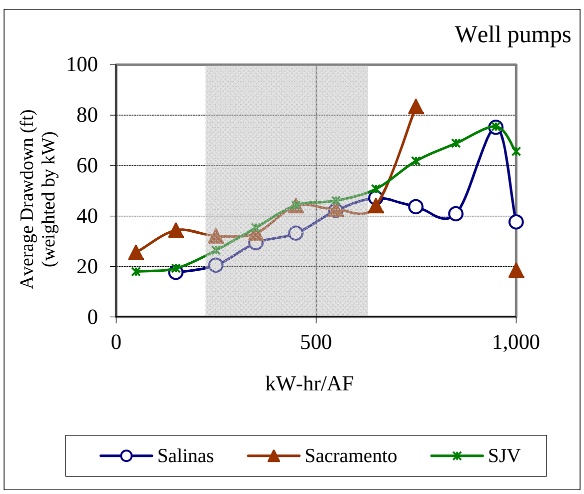


Figure 15. Average Drawdown [ft] (Weighted by Input Power)

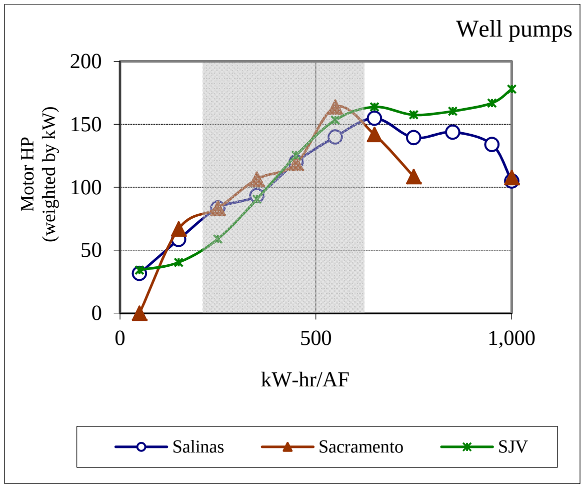


Figure 16. Average Motor HP (Weighted by Input Power)

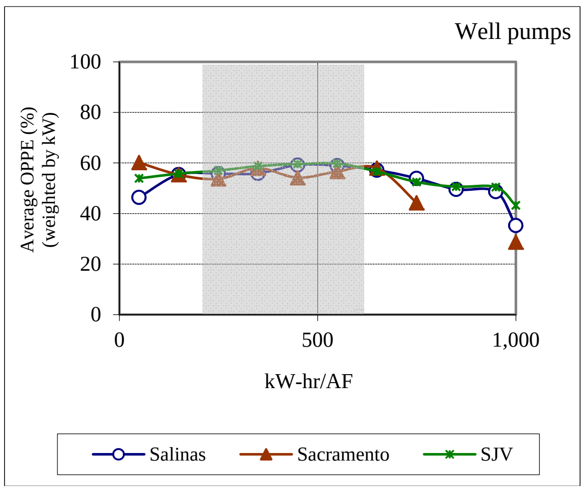


Figure 17. Average Overall Pumping Plant Efficiency (OPPE) [ft] (Weighted by Input Power)

When comparing the data from the three basins to the kWh/AF, some general observations regarding the well pump data can be made:

1. A majority of the well pump tests fall between 200 and 500 kWh/AF.
2. The Sacramento basin well pump tests differ from the well pump tests in other basins at higher (600+) kWh/AF in all categories. No conclusions are drawn from this data due to the small sample sizes in those ranges.
3. The well pumps tested in the Sacramento and Salinas basins have higher average input power in the 200-500 kWh/AF range than the well pumps in the San Joaquin basin. However, the average input power increases with kWh/ah, and the Salinas and San Joaquin basins have more tests in the higher ranges (400+) than the Sacramento basin. This could explain why the Sacramento and San Joaquin basin-wide averages are nearly equal, and the Salinas basin average is slightly higher.
4. Average regional flow rates vary significantly at low (0-300) kWh/AF, but match well at higher (400+) kWh/AF. Only the Sacramento basin has a significant number

of well pump tests in that range (see Figure 10). These low kWh/AF, high flow rate pumps are probably causing the Sacramento basin tests' average flow rate to be so much higher than the test averages in the other basins.

5. The San Joaquin basin's well pump tests do not appear to have a significantly greater drawdown than the other basins (see Figure 15). This can be explained mainly by the distribution of tests. The San Joaquin basin has a significant percent of its tests in the 500-800 kWh/AF range (see Figure 10), and the tests in those ranges have higher drawdown values than the 0-500 kWh/AF ranges and the Salinas basin (which also has a significant percent of its tests in the higher range) and input power (what the average drawdown values are weighted by) than in the 0-500 kWh/AF ranges. This could cause the basin's overall higher value, without making the values in the 200-500 range significantly higher in comparison to the other two basins.
6. The average total dynamic head in each kWh/AF range is almost identical for the three basin averages, even though the average total dynamic head of the Sacramento basin well pump tests was lower than the tests other basins. This is probably due to the fact that the majority of the well pump tests in the Sacramento basin had slightly lower kWh/AF than the well pump tests in the other basins; the lower kWh/AF ranges had lower average total dynamic heads for all basins.
7. The average depth to standing water level increases with the kWh/AF, possibly indicating the effect larger pumps are having on their local water tables.

Regional Comparison by Subbasin

Maps were created characterizing the groundwater subbasins according to available pump data. The Central Valley of California can be divided into three basins (Salinas, Sacramento, and San Joaquin Valley), each divided into a number of subbasins to examine the validity of the regional conclusions. The following maps (Figures 18-25) illustrate the three groundwater basins (and their subbasins) with varying parameters.

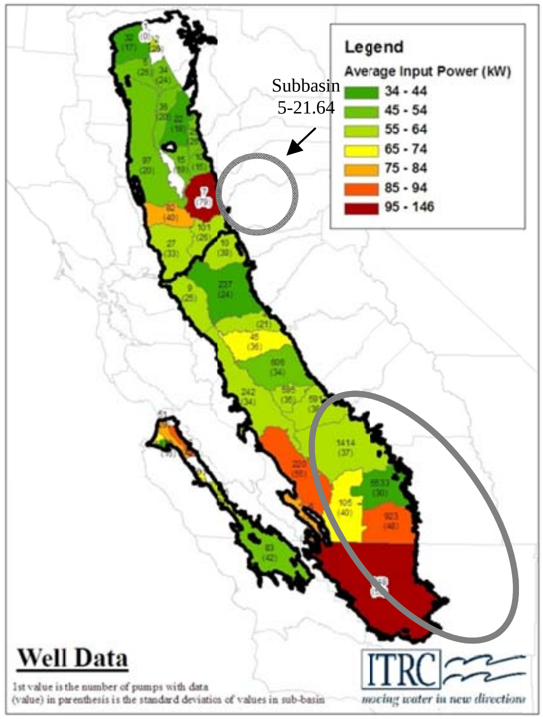


Figure 18. Average Input Power [kW]

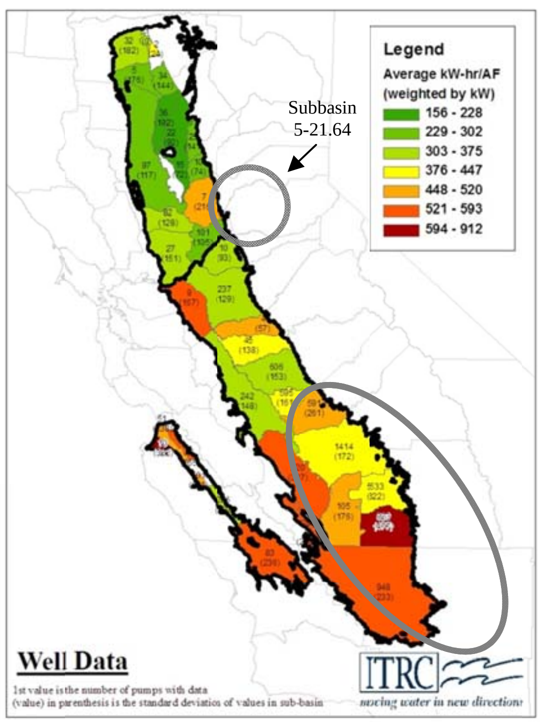


Figure 19. Average kWh/AF (Weighted by Input Power)

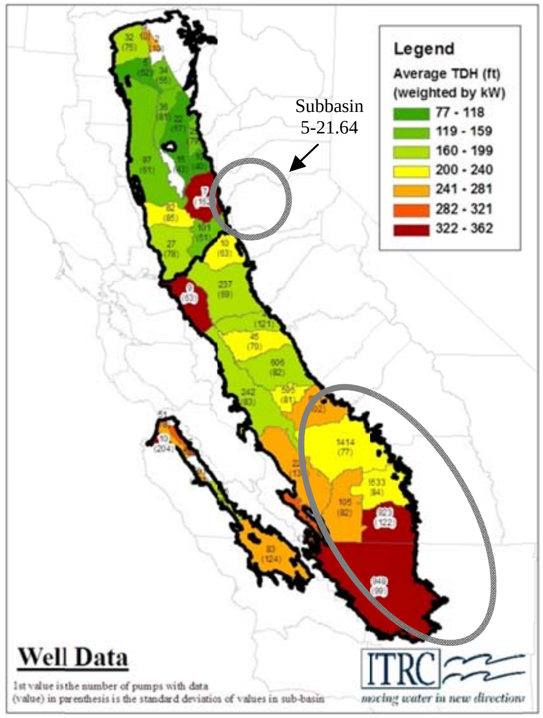


Figure 20. Average Total Dynamic Head (TDH) [ft] (Weighted by Input Power)

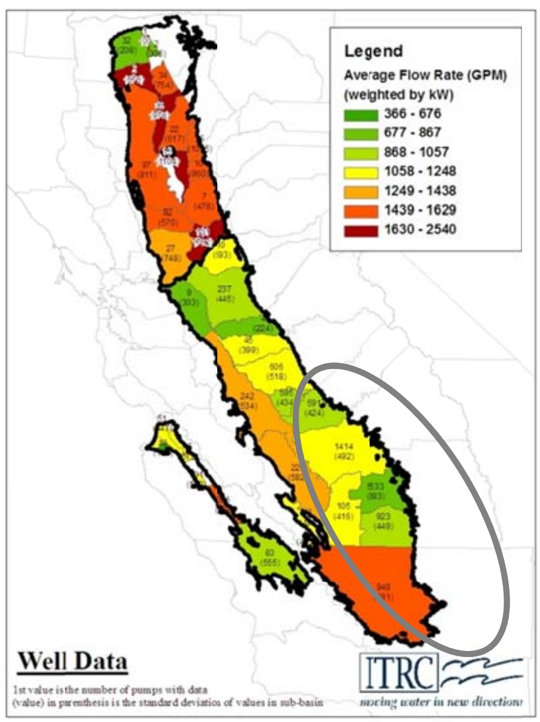


Figure 21. Average Flow Rate [ft] (Weighted by Input Power)

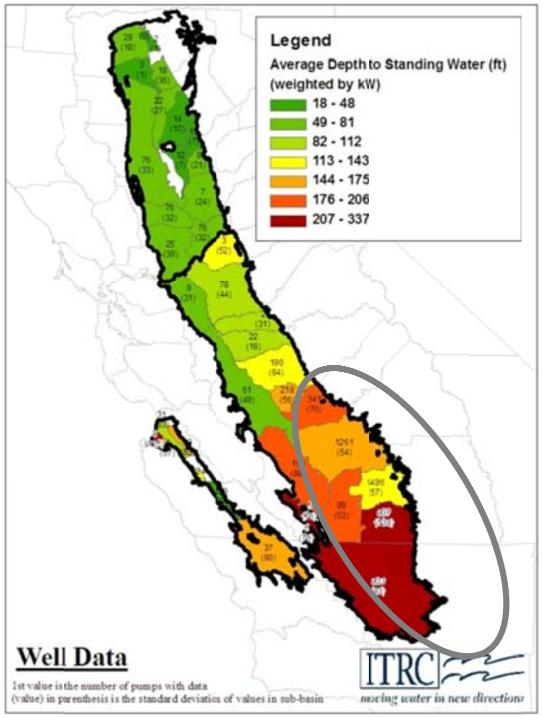


Figure 22. Average Depth to Standing Water Level (SWL) [ft] (Weighted by Input Power)

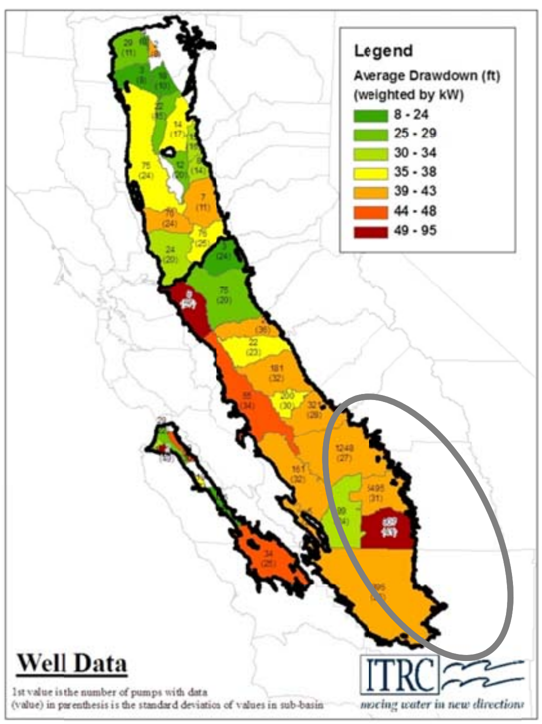


Figure 23. Average Drawdown [ft] (Weighted by Input Power)

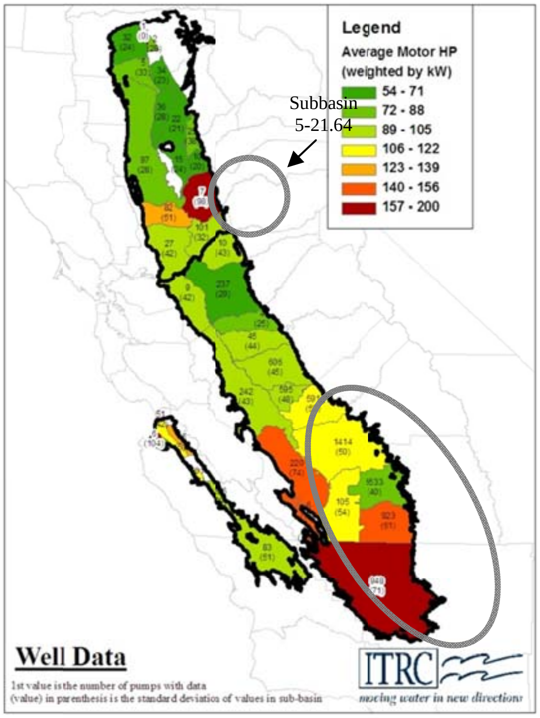


Figure 24. Average Motor HP (Weighted by Input Power)

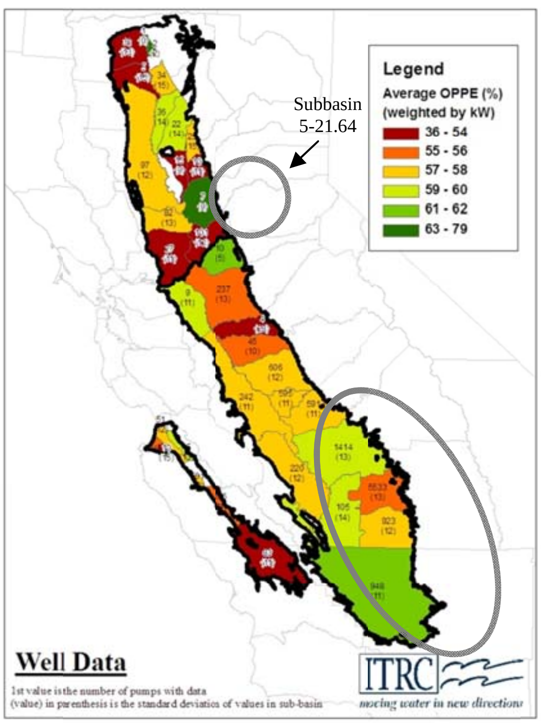


Figure 25. Average Overall Pumping Plant Efficiency (OPPE) [%] (Weighted by Input Power)

When comparing the data from the three basins by subbasin, some general observations regarding the well pump data can be made:

1. There are clear basin trends for average input power, kWh/AF, total dynamic head, flow rate, depth to standing water, and motor HP (it does not appear that certain sub-basins are heavily skewing the data).
2. The Sacramento basin has one subbasin (5-21.64) that has well pump test values that differ greatly from the rest of the basin. This subbasin has only 7 tests, 3 of which are very large pumps (input power greater than 100 kW, motor HP greater than 100, discharge pressure greater than 100 psi, flow rate greater than 1000 GPM, total dynamic head greater than 375 ft, and kWh/AF greater than 500) with high overall pumping plant efficiencies (greater than 68%).
3. The San Joaquin basin appears to have more extreme well pump test values in the southern portion compared to the northern portion.
4. When comparing the overall pumping plant efficiency (OPPE) (a calculation based on the input power, flow rate, and total dynamic head), the Salinas and Sacramento basins' well pump tests have a slightly lower average OPPE than the San Joaquin basin; however, the majority of subbasin average OPPEs can be contained between 54% and 62%.

CONCLUSION

The major conclusions drawn from the well pump test data include:

1. All three basins' well pump tests have very similar average weighted overall pumping plant efficiencies (~56%), with the majority of the values contained between 54% and 62%.
2. A majority of the well pump tests fall between 200 and 500 kWh/AF.
3. There are noticeable trends in data between the Sacramento, Salinas, and San Joaquin basins.
    a. In general, the Salinas basin well pump tests had, in relation to the well pump tests in the other basins:
        i. Slightly higher input power
    b. In general, the Sacramento basin well pump tests had, in relation to the well pump tests in the other basins:
        i. Lower kWh/AF
        ii. Lower total dynamic head
        iii. Higher flow rates
        iv. Lower depths to the standing water level
        v. Slightly lower motor HP
    c. In general, the San Joaquin basin well pump tests had, in relation to the well pump tests in the other basins:
        i. Greater depths to the standing water level
        ii. Higher drawdown
4. The San Joaquin basin's well pump tests had more extreme values in most categories in the southern region as compared to the northern region.

5. The Sacramento basin has one subbasin (5-21.64) that has well pump test values that differ greatly from the rest of the basin. However, data from only 7 tests within this subbasin were found, 3 of which are very large pumps.
6. The average depth to standing water level varies greatly between basins.
7. Within each basin, the average depth to standing water level increases with the kWh/AF, possibly indicating the effect larger pumps are having on their local water tables.
8. About 7% of the Sacramento basin's well pump tests are low (0-100) kWh/AF, high (>2000) flow well pumps.

ACKNOWLEDGEMENTS

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EVAPOTRANSPIRATION OF ALFALFA IN COMMERCIAL FIELDS, CALIFORNIA

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ABSTRACT

Evapotranspiration (ET) was measured for six years (2005 – 2010) in commercial alfalfa fields for a wide range of California environments. Seasonal ET values ranged from 747 to 973 mm for the Intermountain area of northern California, 1080 to 1397 mm for the Sacramento Valley, 1438 to 1509 for the San Joaquin Valley, and 1412 to 1672 mm for the Imperial Valley. These estimates are lower than historically-published values for the Imperial Valley, but higher than historical values for the other locations. Average seasonal crop coefficients ranged between 0.9 and 1.0 for the different environments. However, coefficients variation from about 0.4 to 1.4 within alfalfa harvest periods (typically 30 days) limit**s** the usefulness of real-time crop coefficients for irrigation scheduling. For practical purposes, these data support use of average coefficients of 0.94.

INTRODUCTION

Alfalfa is California's single largest agricultural water user due to the amount grown, typically about 405,000 hectares, and its long growing season. Seasonal alfalfa water applications generally range from 490,000 to 677,000 ha-m.

Commonly-used values of seasonal alfalfa evapotranspiration (ET) or crop water use (referred as historical ET) in California are 1219 mm to 1244 mm in the Sacramento and San Joaquin Valleys, 1930 mm in the Imperial Valley, and 838 mm in the Intermountain Region of northern California. However, sources of these values are not clear. They appear to be the results of experiments conducted in the 1960 and 1970's or calculated as the product of a reference crop ET determined from pan evaporation data and crop coefficients. The crop coefficients appear to have been developed at the University of

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California, Davis using ET data from lysimeter ET data and reference crop ET from pan evaporation data, but no publications appear to exist on this research.

The California Department of Water Resources funded a project with the initial objective of determining the potential of deficit irrigation of alfalfa as a strategy for transferring water used by agriculture from water-rich areas to water-poor areas. As part of this project, the ET of fully irrigated alfalfa was also determined at various locations throughout California.

METHODS AND MATERIALS

Alfalfa ET was determined in commercial fields using eddy covariance and surface renewal energy balance methods. These are micrometeorological techniques that use data on net radiation, air temperature, humidity, wind speed, soil temperature, soil heat flux, and soil water content for calculating ET.

Sites were selected in the Imperial Valley, southern San Joaquin Valley (Kern County), Sacramento Valley (Yolo County), Scott Valley/Shasta Valley (Siskiyou County), and Tulelake (Klamath Basin, Siskiyou County), reflecting the range of climate conditions of the alfalfa production areas in California. Site specific characteristics are in Table 1. Measurements were made during the calendar year for the Sacramento, San Joaquin, and Imperial valleys because of the 12-month growing season at these locations with 5 to 7 harvests. A crop season of mid-March to the end of September was assumed for the Intermountain Region sites where the last harvest generally occurred by the end of September, resulting in three harvests and dormant alfalfa during the winter months. Twenty-four data sets of seasonal alfalfa ET were collected during this experiment.

The alfalfa ET data were compared with a reference crop ET (ET_o) and crop coefficients were calculated as the ratio of ET to ET_o. ET_o was determined from the California Irrigation Management Information System (CIMIS) weather stations for all sites except Scott Valley and Shasta Valley, where no CIMIS stations existed. For these valleys, the reference crop ET was calculated with the Hargreaves method (Hargreaves et al., 1985) using local maximum and minimum air temperature data. A comparison of the Hargreaves ET and CIMIS ET_o using CIMIS data from two sites of the Intermountain Region (Fall River Valley and Tulelake) showed good agreement between the two methods for wind speeds smaller than about 2 m s^{-1}, which occurred 81% of the time for Scott Valley.

Soil water tension was measured using Watermark sensors installed at six-inch depth intervals down to 36 or 48 inches, depending on the site. The sensors were connected to a Monitor data logger with measurements made at 30 to 60 minute intervals.

Table 1. Site-specific characteristics.

Region	Site	Elevation (ft)	Dominant soil types	Irrigation method
Imperial Valley	LM1	-6	Holtville silty clay	Flood
	LM2	-6	Imperial-Glenbar silty clay loam	Flood
	GZ	36	Imperial-Glenbar silty clay loam	Flood
	EL	-43	Imperial-Glenbar silty clay loam	Furrow
	WA	-240	Glenbar clay loam	Flood
San Joaquin Valley	BU	180	Buttonwillow clay	Flood
Sacramento Valley	CH1	50	Meyers clay; San Ysidro loam	Flood
	CH2	50	Capay silty clay; Myers clay;	Flood
	EE	37	Corval loam	Flood
	EW	54	Sycamore silty clay	Flood
Scott Valley	EN	2,700	Settlemeyer loam	Wheel-line
	AR	2,730	Settlemeyer loam	Center pivot
	FI	2,722	Stoner gravelly sandy loam	Center pivot
	FA	2,673	Diyou loam	Center pivot
Shasta Valley	SH	2,624	Louie loam	Center pivot
Tulelake	TU	4,000	Tulebasin mucky silty clay loam	Wheel-line

RESULTS

Evapotranspiration

At all sites, ET increased over time to maximum values and then decreased, as would be expected (fig. 1-3). Values at the beginning and end of the crop season generally were smaller than 2 mm d^{-1} for all sites. Maximum daily ET usually ranged between 6 and 10 mm d^{-1}, depending on the site, with maximum values occurring in June or July. Superimposed over the seasonal trend was the harvest effect, which reduced ET during the harvest to values generally between 2 and 4 mm d^{-1}. ET rapidly increased over time after the first post-harvest irrigation to maximum values, which usually exceeded ET_o just before the next harvest.

Imperial Valley. At site 2007 LM1, trends in daily ET and ET_o were similar over time except during the harvest periods and between DOY 200 to 280 (July 19 to October 7) (fig 1). ET decreased during the harvests, but generally increased rapidly after the first irrigation following harvest and remained higher than ET_o until the next harvest. However, between DOY 200 to 280, daily ET values smaller than ET_o occurred with an initially high ET just after the first post-harvest irrigation followed by decreasing values smaller than ET_o until the next irrigation. After DOY 280 trends in ET and ET_o were similar to those prior to DOY 280.

Similar behavior also occurred at the 2010 GR site until about DOY 220 (August 8), after which daily ET decreased over time to values smaller than ET_o until about DOY 260 (September 17) (fig. 1). Between DOY 220 to 260, no irrigations occurred. After DOY 260, similar ET and ET_o values were found. At site 2010 WA, similar trends in ET and ET_o occurred for the crop season, however, ET was smaller than ET_o during the harvest and ET exceed ET_o after the first post-harvest irrigation until the next harvest (fig. 1). Furrow-irrigated seed alfalfa was grown at 2010 EL (data not shown). In the spring, daily ET was smaller than ET_o for about a one month period due to grazing of sheep.

The mid to late summer behavior found at 2007 LM1 and 2010 GR also occurred at 2008 LM2 and 2009 LM2 (data not shown). This behavior appears to reflect water logging or “scalding” of alfalfa commonly experienced in the Imperial Valley by flood irrigators on heavy soils during the period of extremely hot temperatures with air temperatures between 40 to 45 ^{o}C from mid-to-late summer. During this time period, irrigations continued to occur at sites 2007 LM1 and 2008 LM2. Irrigations were delayed at sites 2009 LM2 and 2010 GR during the waterlogging period, possibly as an attempt to prevent the waterlogging problems. During these periods of waterlogging, the alfalfa appeared to be severely stressed with a light green to grey color and some leaf desiccation. Interestingly, this behavior did not occur at 2010 WA even though the soil was clay loam and the field was flood-irrigated.

Seasonal ET (12 months) ranged from 1412 mm to 1672 mm with three sites exceeding 1600 mm (Table 2), smaller than the historical seasonal ET of 1930 mm. Seasonal ET_o ranged from 1724 to 1860 mm .

San Joaquin Valley. Maximum daily values at site KC were nearly 10 mm d^{-1} for both years (fig. 2). Maximum values occurred during mid-June. Seasonal ET(12 months) ranged from 1438 mm to 1509 mm (Table 2), which were larger than the historical seasonal ET of 1245 mm. Seasonal ET_o was 1447 mm to 1506 mm.

Sacramento Valley. Maximum daily ET of the 2006 CH2 site was generally between 7 and 8 mm d^{-1} (fig. 2). Similar values occurred for sites 2005 CH1, 2007 CH2, and 2008 CH2 (data not shown). In 2010, smaller maximum values between 6 and 7 mm d^{-1} occurred at 2010 EW (fig. 2) and 2010 EE (data not shown) due to an unusually cool summer. During the first 100 days of 2010, considerable day-to-day variability occurred in both ET and ET_o compared to the other sites, reflecting the early season weather behavior of the southern Sacramento Valley in 2010. Occasionally, relatively large daily ET values occurred caused by strong wind from the northwest, referred to as the “north wind”.

Seasonal ET ranged from 1080 mm to 1397 mm, while seasonal ET_o ranged from 1240 mm to 1615 mm (Table 2). The small 2010 values reflect a cooler than normal climate as indicated by the small ET_o value of 2010. The 2010 ET values were smaller than the historical ET, but the other values were larger than the historical value.

Scott Valley/Shasta Valley. Maximum daily ET ranged between 6 and 8 mm d^{-1} for the Scott Valley 2007 EN site (fig. 3). However, for 2008 and 2009, mid-summer values (data not shown) was smaller than those of 2007. The smaller 2008 EN values reflected reduced ET due to smoke in the valley from forest fires, while the smaller ET values at 2009 EN reflected the water management practices of that year, which resulted in delayed irrigations during the early summer. Maximum ET occurred during the first part of July. Wheel-line sprinkle irrigation was used at Site EN.

Higher maximum daily ET values between 8 and 10 mm d^{-1} occurred for the Scott Valley 2010 FJ site due to center pivot sprinkle irrigation (fig. 3). Center pivot irrigation also was used for the Shasta Valley 2009 and for the other 2010 Scott Valley sites, which resulted in higher daily values during the summer (data not shown).

Seasonal ET ranged from 747 mm to 985 mm. The small value reflects the smoke in the valley in 2008 (Table 2). Seasonal ET of the center-pivot irrigated sites exceeded 900 mm most of the time. These seasonal values exceeded the historical value of 838 mm except in 2008.

Tulelake. Maximum daily ET values at the 2007 TU site were generally between 7 and 8 mm d^{-1} (fig. 3). Similar values occurred in 2008 (data not shown). Daily ET values exceeded daily ET_o during the mid-summer growth periods for both years except during the harvest periods. Seasonal ET ranged from 871 mm to 991 mm, which exceed the historical value of 838 mm. (Table 2). Seasonal ET_o ranged from 927 to 1029 mm.

Crop Coefficients

Crop coefficients were minimum (0.43 to 0.72) during the harvest period and maximum (0.99 to 1.30) just before the next harvest as shown for the Imperial Valley 2010 WA, Sacramento Valley 2006 CH2, and the Tulelake 2007 TU sites (fig. 4). Similar behavior occurred at the other sites except during the waterlogging periods of the Imperial Valley sites, where smaller coefficients occurred. Prior to the first harvest and after the last harvest, crop coefficients varied considerably over time, reflecting the variability in ET during those periods. However, using real time crop coefficients (recommended for irrigation scheduling of most crops) is not practical for alfalfa growers to estimate alfalfa ET for irrigation water management purposes because of the crop coefficient variability between harvests. Thus, seasonal average coefficients are recommended (Table 3). Most of the seasonal crop coefficients of the individual sites were between 0.9 and 1.0. Average values were 0.91 for the Imperial Valley, 0.99 for the southern San Joaquin Valley, 0.94 for the Sacramento Valley, 0.94 for Scott Valley and 0.98 for Tulelake.

Average regional crop coefficient differences were not statistically significant. Also, no trend with location existed in the data. The statewide average value was 0.94, similar to the value of 0.95 recommended by Doorenbos and Pruitt (1977) for California climates.

CONCLUSIONS

Seasonal ET values determined from climate and soil data collected in commercial fields differed from the historical ET generally used for alfalfa in California. Seasonal values for the Imperial Valley were smaller than the historical value, but they were larger than the historical ET for the Sacramento/San Joaquin Valley and the Intermountain Regions. Average crop coefficients determined for the commercial field data were similar to the historical recommended values.

Note that while seasonal ET values found from these measurements are higher than the historical values (except for the Imperial Valley), the average crop coefficients are similar to the historical value determined for California. This behavior appears to reflect differences in ET_o values between the CIMIS ET_o currently used and the ET_o values used in the 1960's and 1970's. Better meteorological equipment and equations for calculating ET_o from the meteorological instruments coupled with a statewide network of monitoring stations in California has greatly improved estimates of $ET_{o,}$ generally increasing annual estimates of ET_o by 10 to 15% above those used 30 years ago (Jones et.al., 1999; Pruitt et al., 1987). This is consistent with our observation of increased alfalfa ET while maintaining average crop coefficient values close to the old standard of 0.95.

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Table 2. Measured seasonal ET and seasonal ET_o for each site/year and historical ET for each region.

Region	Site	Year	Age of alfalfa (years)		Seasonal ET (mm)	Seasonal Reference ET (mm)	Historical ET (mm)
Imperial Valley	LM1	2007	3		1,458	1,859	1,930
	LM2	2008	2		1,653	1,862	
	LM2	2009	3		1,412	1,724	
	GZ	2010	2		1,652	1,860	
	EL	2010	2		1,503	1,777	
	WA	2010	2		1,672	1,777	
San Joaquin Valley	BU	2007	2		1,438	1,447	1,245
	BU	2008	3		1,509	1,506	
Sacramento Valley	CH1	2005	3		1,280	1,615	1,219
	CH2	2006	2		1,382	1,420	
	CH2	2007	3		1,397	1,473	
	CH2	2008	4		1,280	1,509	
	EE	2010	3		1,177	1,240	
	EW	2010	4		1,080	1,240	
Scott Valley/Shasta Valley	EN	2007	2		973	1,117	838
	EN	2008	3		747	1,082	
	EN	2009	4		843	1,026	
	FI	2009	5		985	1,026	
	SH	2009	4		985	1,044	
	AP	2010	5		917	950	
	FI	2010	2		947	950	
	FA	2010	6		881	950	
Tulelake	TU	2007	4		991	1,029	838
	TU	2008	5		871	927	

Table 3. Average minimum and maximum crop coefficients during the crop season and the average seasonal crop coefficient.

Site	Site	Year	Minimum	Maximum	Average
Imperial Valley	LM1	2007	0.43	0.99	0.83
	LM2	2008	0.66	1.08	0.91
	LM2	2009	0.72	1.05	0.90
	GZ	2010	0.48	1.15	0.94
	EL	2010	0.55	1.10	0.91
	WA	2010	0.64	1.13	0.98
		Ave	0.58	1.08	0.91
San Joaquin Valley	BU	2007	0.62	1.25	0.96
	BU	2008	0.65	1.08	1.03
		Ave	0.63	1.16	0.99
Sacramento Valley	CH1	2005	0.49	1.14	0.92
	CH2	2006	0.56	1.11	0.93
	CH2	2007	0.65	1.33	1.04
	CH2	2008	0.60	1.05	0.88
	EE	2010	0.64	1.06	0.98
	EW	2010	0.50	1.06	0.89
		Ave	0.57	1.12	0.94
Scott Valley/Shasta Valley	EN	2007	0.59	0.96	0.90
	EN	2008	0.36	0.94	0.69
	EN	2009	0.48	0.98	0.85
	FI	2009	0.47	1.09	0.99
	SH	2009	0.65	1.22	0.90
	AP	2010	0.56	1.17	0.99
	FI	2010	0.47	1.20	0.98
	FA	2010	0.46	1.13	0.90
		Ave	0.51	1.09 1.16[1]	0.94
Tulelake	TU	2007	0.50	1.30	0.99
	TU	2008	0.56	1.23	0.96
		Ave	0.53	1.26	0.98
	Doorenbos and Pruitt, 1977				
Humid			0.50	1.05	0.85
Dry			0.40	1.15	0.95
Strong wind			0.30	1.25	1.05

[1] Center-pivot sprinkle system only

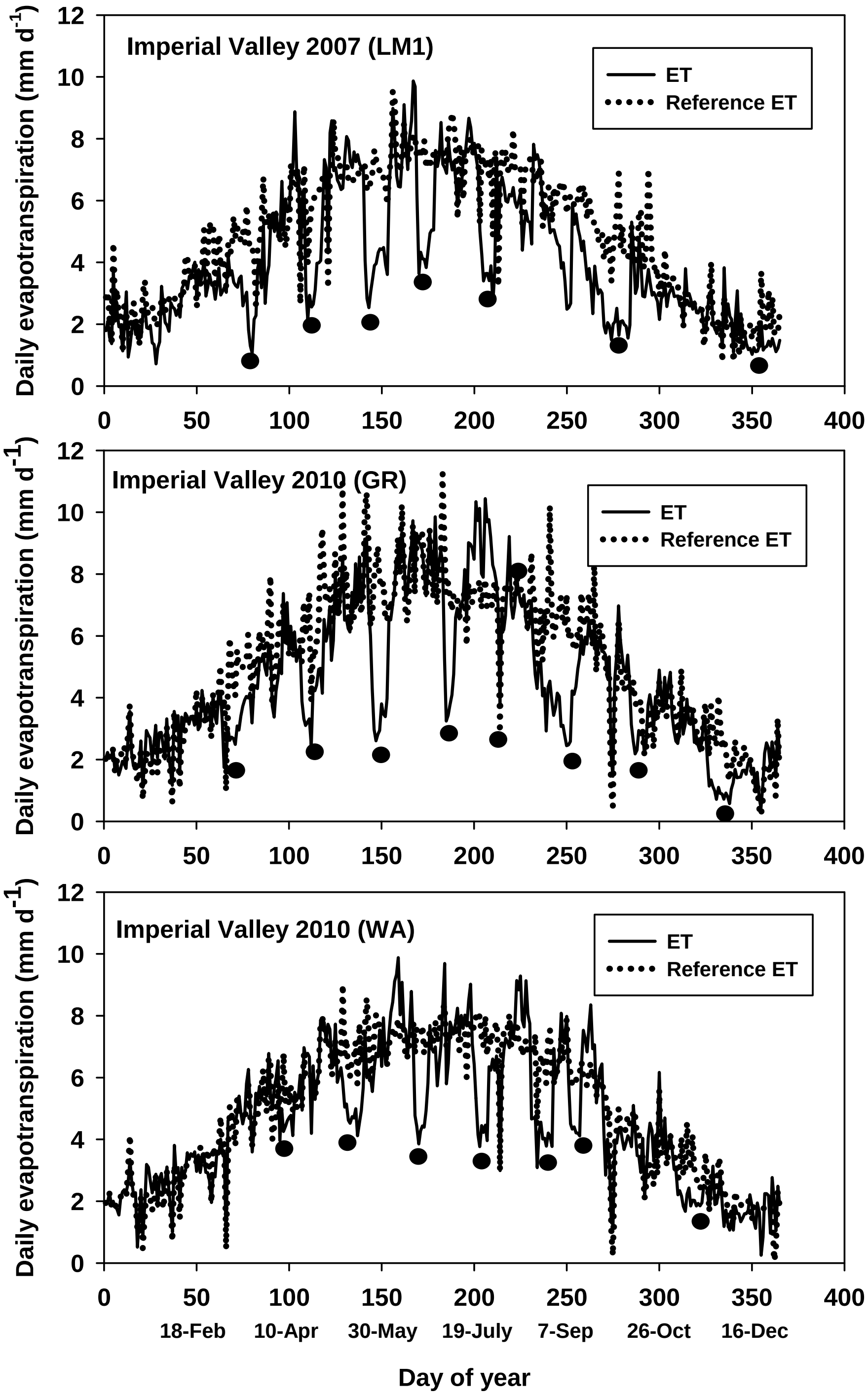

Figure 1. Daily alfalfa and reference evapotranspiration for the Imperial Valley 2010 LM1, 2010 GR and 2010 WA sites. The black dots are the harvests.

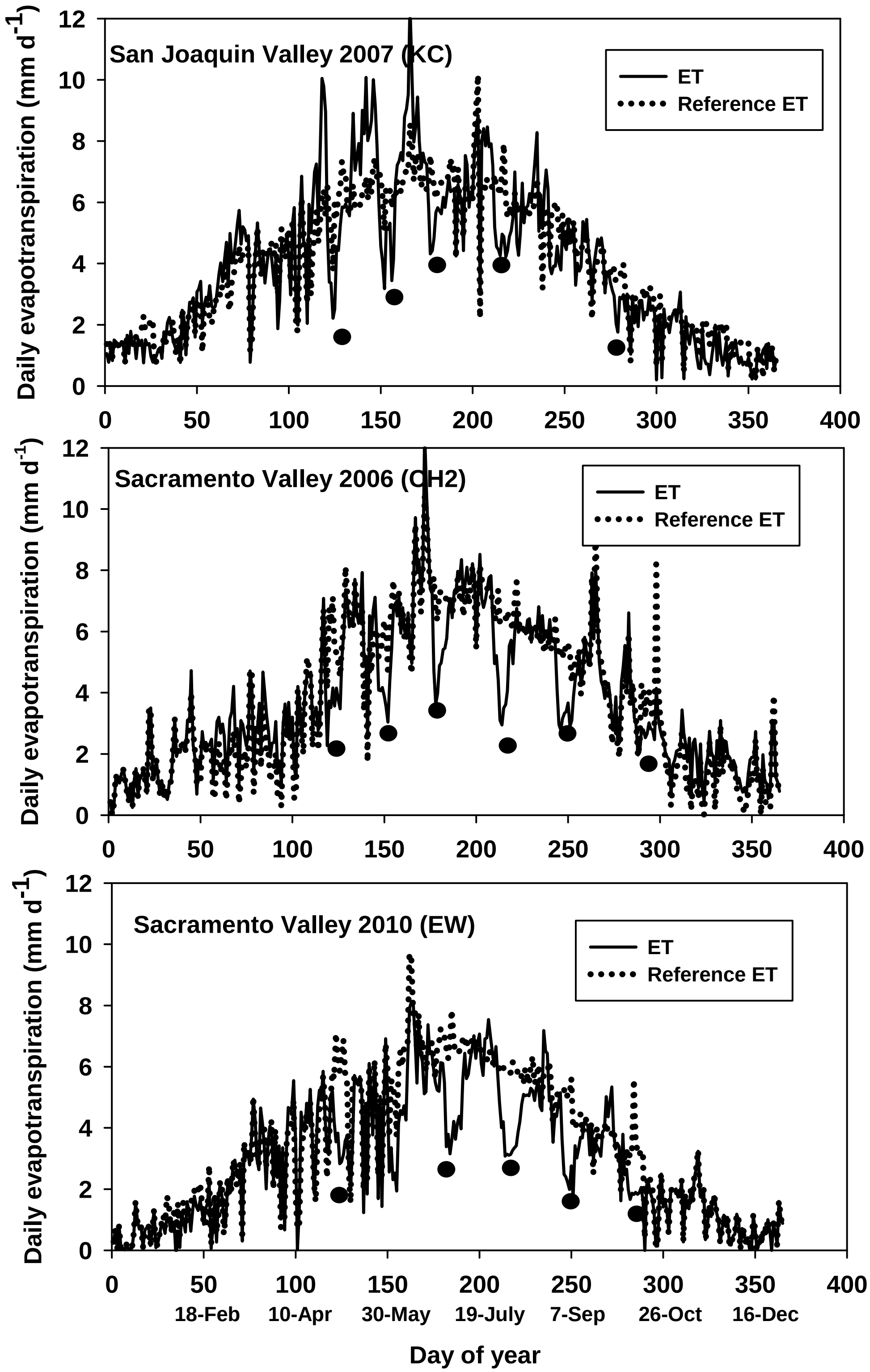

Figure 2. Daily alfalfa and reference evapotranspiration for the San Joaquin Valley 2007 KC, Sacramento Valley 2006 CH2, and Sacramento Valley 2010 EW sites. The black dots are the harvests.

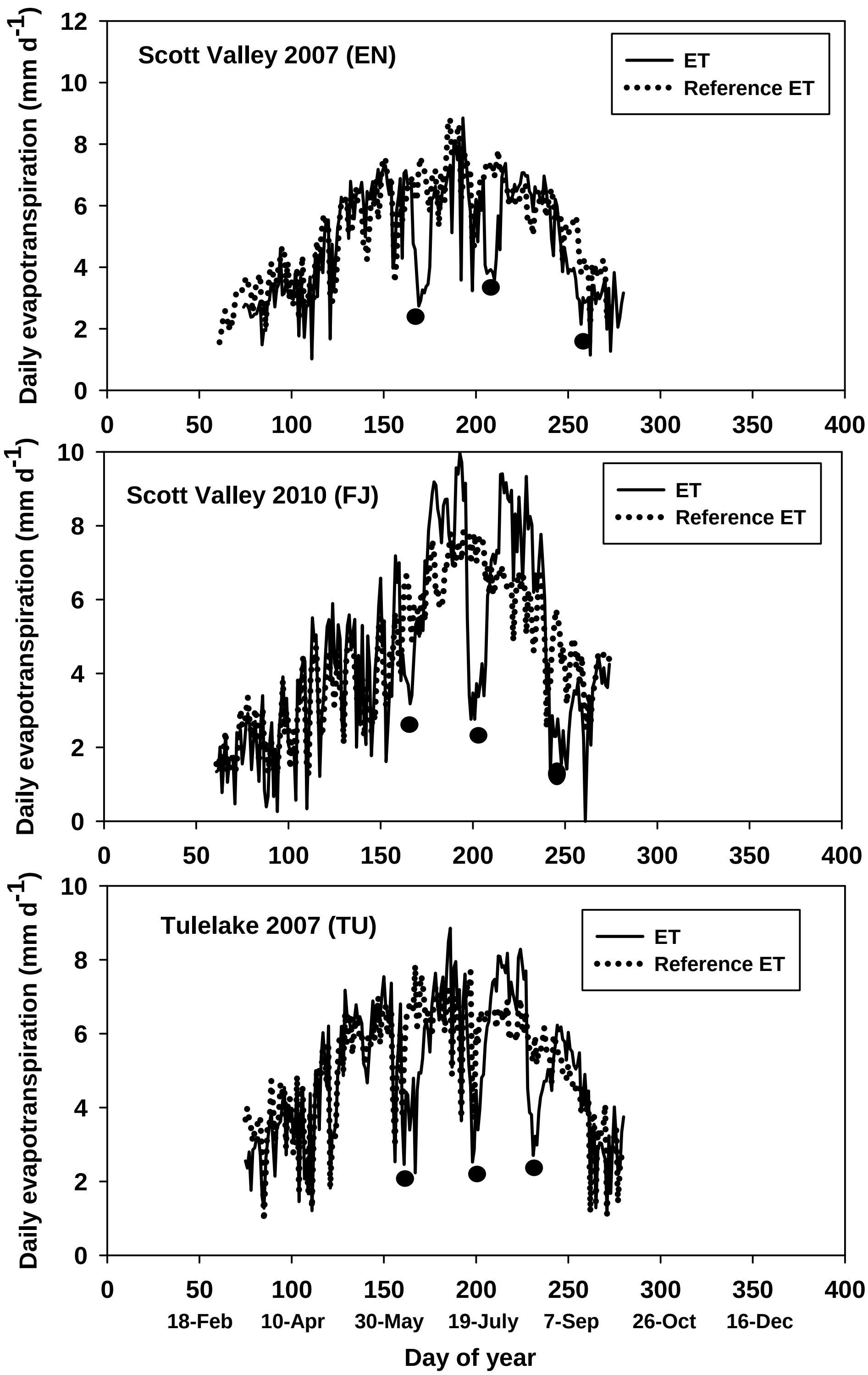

Figure 3. Daily alfalfa and reference evapotranspiration for Scott Valley 2007 EN, Scott Valley 2010 FA, and Tulelake 2007 TU sites. The black dots are the harvests.

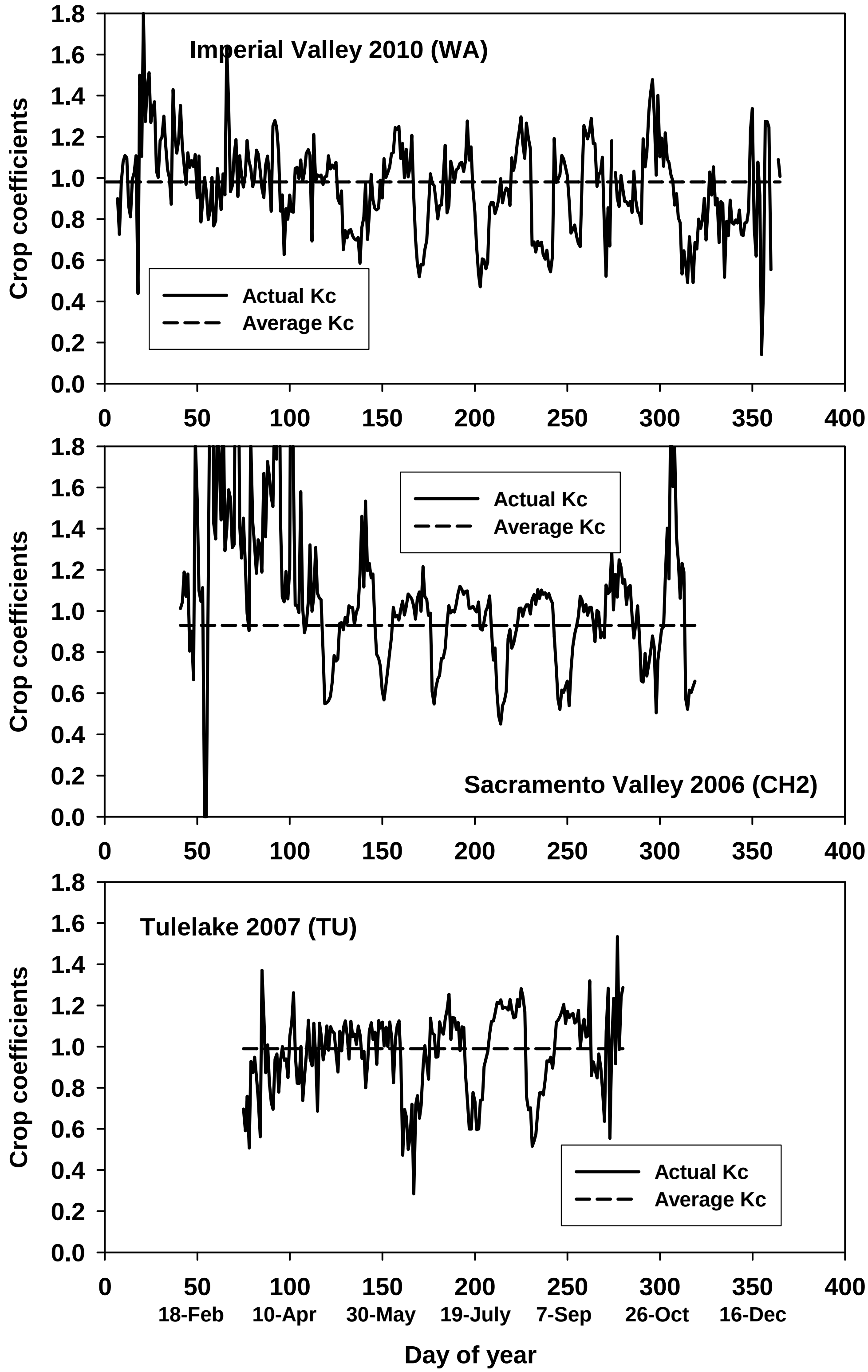

Figure 4. Daily and average crop coefficients for the Imperial Valley 2010 WA, Sacramento Valley 2006 CH2, and Tulelake 2007 TU sites.

REGULATED DEFICIT IRRIGATION OF WINE GRAPES

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ABSTRACT

A two-year project evaluated deficit irrigation strategies for Cabernet Sauvignon grapes grown in Paso Robles, California. The experiment was on a 31 ha site containing 12 individual fields and used a randomized complete block design with three irrigation treatments and two replications. The growing season was divided into three growth stages; bud break to fruit set, fruit set to fruit set +3 weeks, and fruit set +3 weeks to harvest. During the second stage from fruit set to +3 weeks, the crop water requirement was fully met for all treatments. Deficit irrigation was proposed for the growth stages prior to and after the critical stage 2. The three irrigation treatments were as follows: treatment one was considered fully irrigated throughout the growing season in both years. In 2009 treatment 2 received 75% of ET_c during the first stage and 50% of Et_c during the third stage; and treatment 3 received 50% in both the first and third stage. In 2010 treatment 2 received 50% of ET_c in stages 1 and 3 and treatment 3 got 25% of ET_c in stages 1 and 3. Data collected included applied water, midday leaf water potential, total yields, cluster weight, berry weight, and juice quality parameters including BRIX, pH, color density and tannin index. The harvest data were collected on 10 contiguous vines in each replication. Results demonstrated no significant negative impacts on yield and quality in both years. There was a 37% water savings in 2009 and a 53% savings in 2010 when comparing treatment 3 to the fully irrigated treatment.

INTRODUCTION

Grapes are the highest value perennial specialty crop in the U.S. An industry-sponsored economic survey estimated that U.S. grape products are valued at $162 billion (MKF, 2007). The semi-arid regions of California, Oregon, and Washington account for greater than 90% of U.S. grape production and more than 9% of global grape output (4th after France, Italy and Spain). There are currently 319,000 ha of grapes under production in California with approximately 194,000 ha devoted to wine grapes, 33,200 ha to table grape production, and 91,900 ha to raisin production.

In 2005, the economic impact of California wine production was estimated at $51.8 billion. This economic activity contributes more than $3 billion annually to California's state and local revenues from excise, income, property, and sales taxes. As California's grape growers compete globally their future success will hinge upon well-informed policies and competitive adaptations for sustainable viticultural practice based on sound science.

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Table grapes, raisin grapes and wine grapes all require different yields and quality standards for profitability. Table and raisin grapes are often fully irrigated, while wine grapes are often deficit irrigated to control excess vegetative vigor. Thus, the potential for water savings based on restricted irrigation during specific growth stages varies between each type of grape and each end product's quality parameters. Conservative estimates of the water required for grape production in California are in the range of 2.33 billion cubic meters per year.

Practices that are imperative for sustainable agriculture under water scarcity include: the refinement of water requirements; improvements in the scheduling of irrigation events, and inclusion of regulated deficit irrigation and partial root zone drying. Reducing applied irrigation while producing comparable yields and yield quality can reduce overall agricultural water needs, providing a solution to temporary or long-term water scarcity.

Research has demonstrated that there are periods during the growth stages of perennial crops in which irrigation can be reduced and water stress can be applied with minimal effect on yield (Chalmers, Mitchell *et al*., 1981; Chalmers, Burge *et al*., 1986; Goldhamer, Viveros *et al*., 2006; Costa, Ortuno *et al*., 2007; Perez-Pastor *et al*., 2009). Williams et al. (2003) demonstrated that maximum yields of Thompson Seedless grapes could be achieved with 80% of the ET_c.

The objectives of this research were; (1) to determine the potential for water savings through deficit irrigation and (2) determine the impact of deficit irrigation on yield and quality of wine grapes.

MATERIALS AND METHODS

This research was conducted on a 31 ha site containing 12 individual fields located on the J Lohr Vineyards at Paso Robles, California. The statistical design was a randomized complete block design with two major blocks separated on the basis of soil types with three irrigation treatments and two replications within a block (Fig. 1). The field layout is given in Fig. 1. One block was located on a sandy loam over clay (San Ysidro series) and the second was on a sandy loam over gravely silty clay (Arbuckle series). Three plots were instrumented with a water meter and electrical conductivity probe. These plots are PR 10-1-5, PR 10-1-6 and PR 10 -1-7 and are shown on Fig. 1.

The crop being grown in this research is a Cabernet Sauvignon wine grape, clone seven on rootstock 5C. It was planted in 1997 with a 3 m x 1.8 m spacing between the rows and within row between vines. It is a T trellis type canopy with vines pruned to 3 to 4 canes each and sprawl management.

In 2009 irrigation was done on a weekly basis and was equal to the projected water use for the upcoming week based on historical weather data. The depth of irrigation was based on the potential evapotranspiration measured (ETo) modified by a crop coefficient based on growing degree days with a base of 50°F. The ET_o was determined by a local weather station network. In 2009 the crop coefficient was also based on percent canopy shaded area measured with the Paso panel (Battany 2009). The shaded area relationship is

$$K_c = -0.008 + 0.017 * SA\% \qquad (1)$$

where K_c is the crop coefficient and SA% is the percent shaded area (Williams and Ayars, 2005). In 2010 irrigation was done on a weekly basis and was designed to replenish the crop water use from the previous week.

The irrigation treatments were designed to provide variable irrigation amounts through three stages of grape production. The first stage was from bud break to fruit set, the second stage was from fruit set to three weeks post fruit set, and the third stage was from three weeks post fruit set to harvest. Irrigation was to be initiated when leaf water potential reached a -1.0 MPa. The depth of irrigation was determined as a percentage of the daily crop water use and varied depending on the growth period. The target irrigation treatments for 2009 and 2010 are summarized in Table 1. The variable depth of application was achieved by adjusting run time.

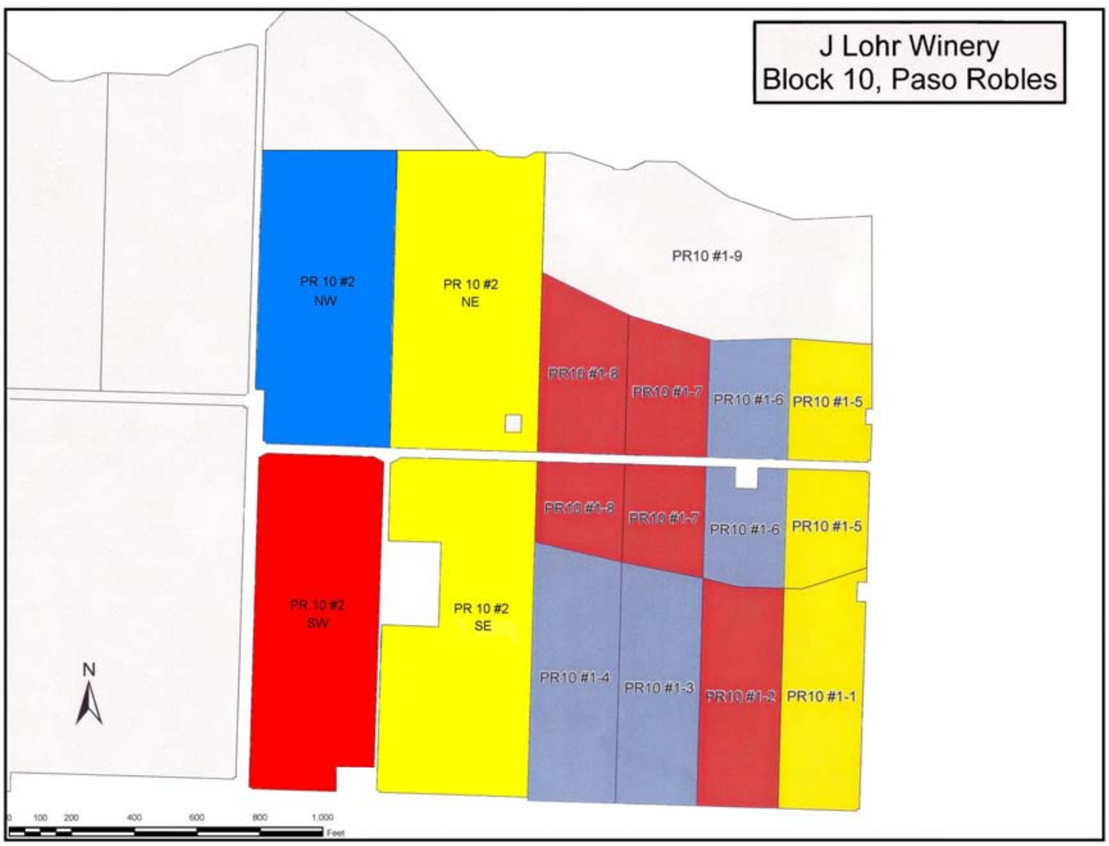

Figure 1. Field layout of deficit irrigation project on J. Lohr vineyards.

Table 1. Summary of target irrigation treatments showing percentage of crop water use for stage 1- bud break to fruit set, stage 2 – fruit set to 3 weeks post set, stage 3 – 3 weeks post set to harvest.

Year	Treatment	Stage 1	Stage 2	Stage 3
2009	TRT 1	75%	100%	75%
	TRT 2	75%	100%	50%
	TRT 3	50%	50%	50%
2010	TRT 1	75%	75%	75%
	TRT 2	50%	75%	50%
	TRT 3	25%	75%	25%

Leaf water potential was measured at midday using a pressure chamber on the day prior to irrigation. The shaded area was also measured at this time. Harvest data were collected on 10 contiguous vines for detailed analysis of fruit size and quality and effects on canopy. The data included number of clusters per vine, weight of fruit per vine, average cluster weight, and average berry weight. In 2010 additional data included the number of canes per vine, the pruning weights and the yield of fruit versus pruning weight. A single row in each plot was used for harvest and wine making. Fruit quality analysis includes BRIX, pH, total acidity (TA), color density, and tannin index. Statistical analysis was done using a mixed procedure with a comparison of the least square means across the irrigation treatments.

RESULTS

The summary of major physiological milestones for 2009 and 2010 are summarized in table 2.

Table 2. Physiological dates for 2009 and 2010.

Bud break	4/8/2009	4/10/2010
Bloom	6/1/2009	5/29/2010
Fruit set	6/10/2009	6/14/2010
Veraison	8/7/2009	8/11/2009
Harvest	10/1/2009	10/29/2010

With the exception of the harvest dates all of the other physiological milestones occurred at approximately the same time in both years. This is typical of the environment in California. The delay in harvest in 2010 was the result of cold wet weather occurring at the end of September.

The actual percentages of ETc values for the applied water for each stage are summarized in Table 3 with the actual water depth amounts in Table 4. In 2010 in stage 1 for all treatments there was a single irrigation and rain that met the crop water requirement until fruit set. The calculated 100% crop water use for the time from bud break to harvest was 483 mm in 2009 and 374 mm in 2010. All treatments received less than the computed full irrigation in both years. The water use ranged from 39 to 61% of the total ET_c in 2009 to 32 to 66% of the total in 2010.

Table 3. Actual percentages of crop water use for 2009 and 2010

Year	Treatment	Stage 1	Stage 2	Stage 3
2009	TRT 1	60 %	118 %	79 %
	TRT 2	60 %	118 %	49 %
	TRT 3	40 %	76 %	49 %
2010	TRT 1	81 %	74 %	65 %
	TRT 2	74%	74 %	46 %
	TRT 3	74%	74 %	23 %

Table 4. Applied irrigation water by deficit irrigation growth stages and total applied water in millimeters (mm)

Year	Treatment	Stage 1 (mm)	Stage 2 (mm)	Stage 3 (mm)	Total (mm)
2009	TRT 1	22	76	198	296
	TRT 2	22	70	122	214
	TRT 3	16	50	122	188
2010	TRT 1	41	31	174	246
	TRT 2	27	31	124	182
	TRT 3	27	31	63	121

The cumulative applied water use and evapotranspiration are given in Fig, 2 for 2009 and Fig. 3 for 2010. In 2009, Treatments 1 and 2 have similar depths of applied water until three weeks after fruit set at which time they separate while treatment 3 has lower amounts of applied water throughout the early developments and thus is separated very early from the other two treatments. In 2010 there is no separation of applied water until three weeks past the fruit set at that time then the differences in the irrigation strategy begin to develop for the total applied water.

The resulting leaf water potentials for each of the treatments are given in figures 4 and 5 for 2009 and 2010. In both years the maximum stress levels occurred in treatment three and at the end of the growing season and there was very little difference between years. In 2009 the maximum stress level was less than -1.3 MPa and approximately -1.4 MPa in 2010. These are not excessive stress levels and occurring late in the season have minimal impact on yield. The strategy for stress management by J. Lohr vineyards is to induce stress from set till veraison, then decrease stress from veraison till harvest. The LWP in both years is in the range of moderate stress and occurred during the period from veraison to harvest.

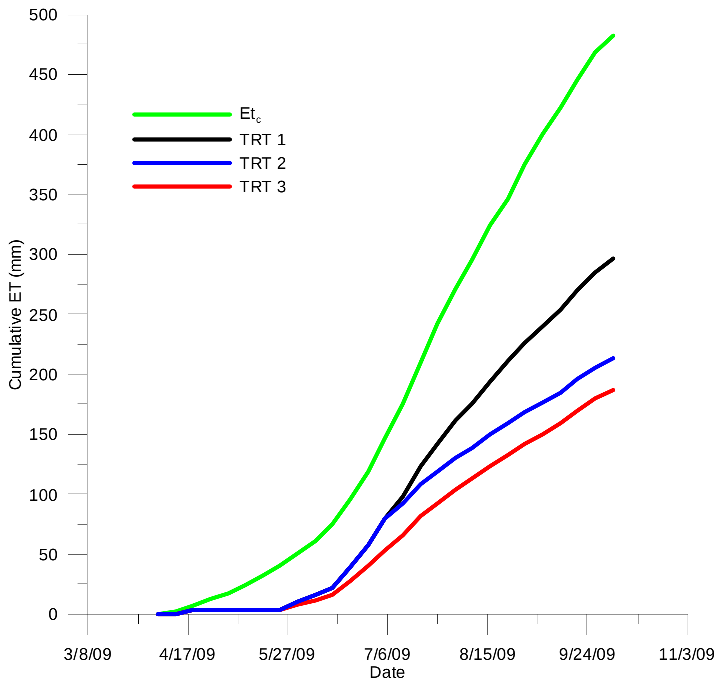

Figure 2. Cumulative evapotranspiration and applied water in 2009 for 3 deficit irrigation treatments.

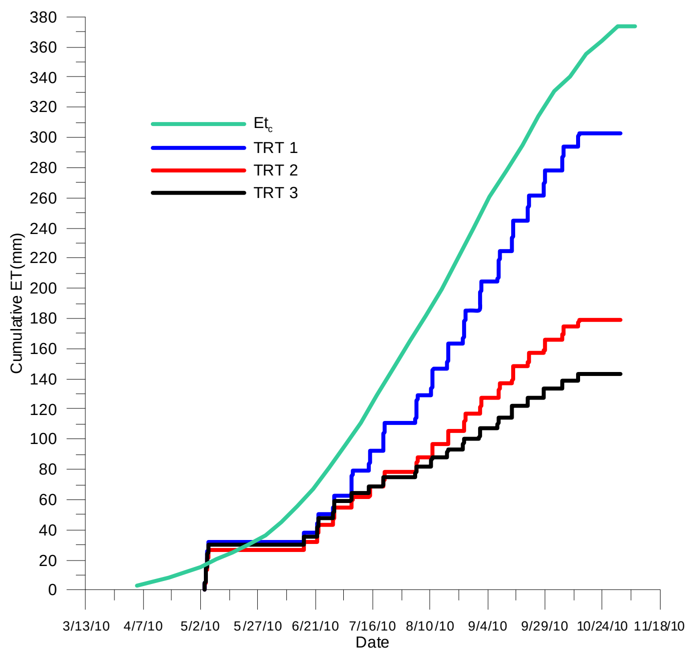

Figure 3. Cumulative evapotranspiration and applied water in 2010 for 3 deficit irrigation treatments.

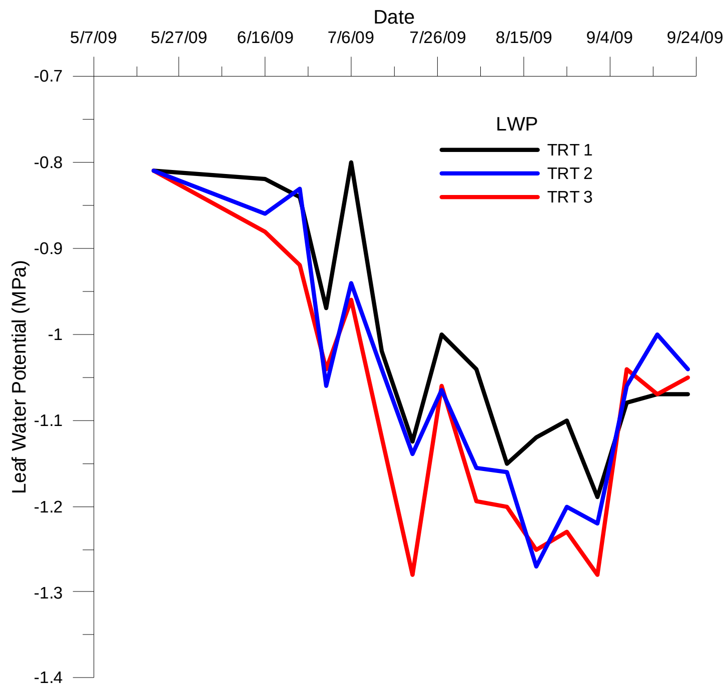

Figure 4. Leaf water potential response to deficit irrigation strategies in 2009

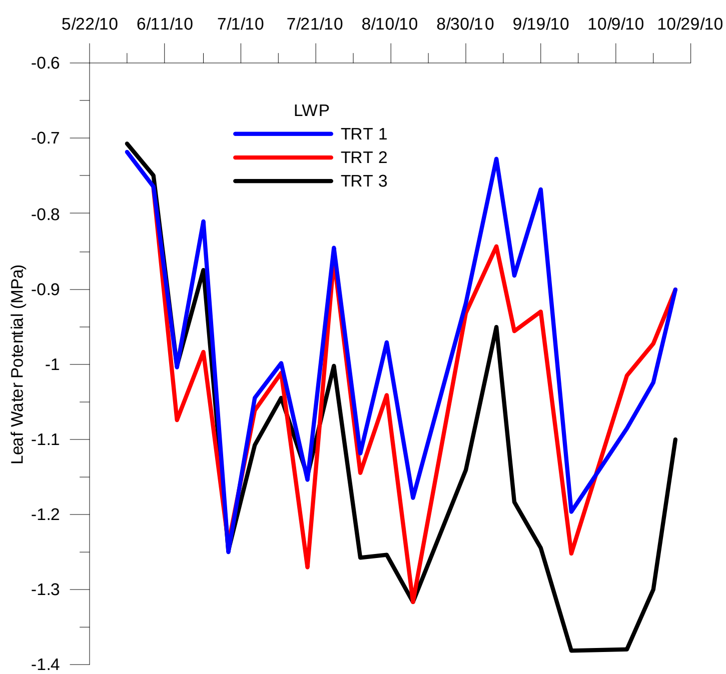

Figure 5. Leaf water potential response to deficit irrigation strategies in 2010.

The yield data for 2009 and 2010 are given in tables 5 and 6, respectively.

Table 5. Summary of average yield per vine and cluster weight.

2009	Ave berry wt (g)	Ave # clusters/vine	Ave kg fruit/vine	Ave kg/cluster
TRT 1	0.95	82.98	8.81	0.11
TRT 2	0.97	80.40	8.32	0.10
TRT 3	0.95	73.05	7.05	0.10

Table 6. Summary of average yield per vine and cluster weight.

2010	Ave berry wt (g)	Ave # clusters/vine	Ave kg fruit/vine	Ave kg/cluster
TRT 1	0.96	78.38	11.13	0.14
TRT 2	0.98	72.98	11.48	0.16
TRT 3	1.03	77.10	12.10	0.16

In comparing the two years data for average number of clusters per vine and the average berry weight there is little difference from year to year. In 2010 the average weight per vine and the cluster weight were larger than in 2009. Statistical comparisons within a given year showed that there was no difference in the berry weight, clusters per vine, average cluster weight, or average yield per vine.

The average values for the juice sugar content (°Brix), pH and titratable acidity (TA) are given in table 7**.** There were no statistical differences between the parameters within a given year. There was a difference in the sugar content between 2009 and 2010. This probably reflects the environmental conditions prior to harvest with the cool weather in 2010 not being conducive to sugar production.

Table 7. Summary of juice quality parameters

Year	Treatment	Brix	pH	TA (g/L)
2009	TRT 1	26.83	3.72	5.15
	TRT 2	26.60	3.73	5.13
	TRT3	26.43	3.73	5.14
2010	TRT 1	23.13	3.55	4.96
	TRT2	23.25	3.52	4.88
	TRT3	22.63	3.47	5.15

The color density (CD) and the tannin index (Ti) are also important parameters for characterizing the potential wine quality. The CD/Ti is calculated as the ratio of the values of CD_p and Ti_p multiplied by 10. These are given in Table 8 for years 2009 and 2010. These values are used by the wine maker to decide the quality of wine that will be made. The CD ranges from 5 to 15 and the TI from 30 to 60 with a resultant values range from 1 to 2.5. Juice with the higher index values will most likely be used in premium wines.

Table 8. Summary of color density (CD) and tannin index (Ti) and the ratio for each treatment in 2009 and 2010.

		CD	Ti	CD/Ti
2009	TRT 1	6.2	41.5	1.5
	TRT2	6.7	44.3	1.5
	TRT3	6.4	43.4	1.5
2010	TRT1	5.5	32.3	1.7
	TRT2	6.2	33.1	1.8
	TRT3	7.6	37.1	2.1

A parameter that relates to the balance between the vine canopy and the fruit production is the ratio of the yield weight to pruning weight. The 2010 values are given in table 9. Desirable ratios generally range from 5 to 10 for cabernet sauvignon with J Lohr using the range of 5 to 7 as their goal.

Table 9. Summary of the pruning yield ratio for 2010.

2010	Ave Number canes/vine	Ave Wt pruning/vine kg	grams/cane	Yield/Pruning Ratio
TRT1	34.5	1.2	34.2	10.3
TRT2	33.5	1.2	35.6	10.1
TRT 3	37.5	1.2	32.1	9.7

DISCUSSION

For each year there was approximately the same amount of applied water in the full irrigation treatments (TRT 1). There was 109 mm less Et_c in 2010 compared to 2009 during the growing season. However, there were considerable differences in applied water between treatments two and three in 2009 and 2010. In 2009 treatment three had a 37% water savings compared to the fully irrigated treatment one and treatment two had a 28% savings compared to treatment one. In 2010 the comparable savings for treatments three and two compared to treatment one were 53% less and 41% less than the applied water for treatment one.

The reduced irrigation amounts did not affect the total yield in 2010 compared to 2009. This was a result of good rainfall in the previous winters. There was approximately 160 mm in the winter prior to the 2009 vintage and 230 mm prior to the 2010 vintage. In fact, there were larger yields in 2010 than in 2009. The total number of clusters per vine was lower in 2010 compared to 2009, but the average cluster weight was higher. The berry size was similar in both years. In 2009 there was a decrease in kg fruit per vine with decreasing mm of water applied. However, in 2010 this decrease was not seen.

The color density to tannin index and yield to pruning ratio are other parameters that are used to manage the vineyard and to characterize the water management strategy. The treatment three in 2010 had the highest color density and the most desirable color density to tannin index ratio of all treatments in 2010, not so in 2009. This is indicative of a potentially high-quality grape and wine derived from it. The yield to pruning ratio is about 10 for each of the treatments across both years. This is the upper end of the range that is considered for good production in Cabernet Sauvignon grapes. This was an indication that the vines were over-cropped relative to the canopy size. In 2011, the vines were pruned to 3 canes to lower the potential yield and bring this ratio into better balance.

CONCLUSION

Deficit irrigation strategies for wine grapes that are designed to be implemented beginning three weeks after fruit set resulted in significant water savings without harm to the crop yield or quality.

Deficit irrigation may be possible prior to fruit set in dry years but the potential water savings will be a function of early season irrigation and stored soil water. Rainfall and stored soil water are important components of a water management strategy and will determine potential deficit water management strategies.

Under the conditions of this trial we achieved up to 50% water savings without detrimental affects on yield or quality over the two year period; however, longer duration studies that include drier winters may achieve different results.

ACKNOWLEDGEMENTS

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EFFECTS OF USE OF GIS AS A REAL TIME DECISION SUPPORT SYSTEM FOR IRRIGATION DISTRICTS IN TEXAS

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ABSTRACT

Most irrigation districts use GIS primarily for simple organization of spatial data. GIS is often put on a lower priority and managed by part-time personnel, which leads to datasets being out-of-date and disconnected from the water daily management. An effective use of GIS is integration with district operations as a real time decision support system.

This paper discusses the development of GIS as a real time decision support system for two irrigation districts in the region of Texas along the Mexican border. Further improvement was made in the Brownsville Irrigation District project, which started in 2009, by introducing an efficient data transfer and by managing all data through a SQL server database. The Cameron County Irrigation District No 2 project started in 2010. This project includes an on-line tool with dynamic and static maps. The dynamic maps display real time Rubicon gate data (on/off, current flow, upstream and downstream water level, and gate position) and water account status (e.g. pending orders, payment delinquents, water balances), and they are designed to assist district personnel with water scheduling and management. The static maps enable a friendlier and quicker access to the frequently used data.

Project work resulted in the identification of limits in the existing database, and recommendations for further improvement. In this paper the process of implementing the projects and the problems encountered, and their effects on the district activities will be presented. Examples of effects include changes in the water management organization, upgrades to new technology, and water and cost savings.

INTRODUCTION

Irrigation districts in Texas are aware that more is to be done in terms of efficiency and data management, and that GIS can be a useful tool. SCADA systems and online information are more being used and linked to GIS (Fipps and Leigh, 1998, Fipps and Leigh, 2003, Bonaiti and Fipps, 2010). The integration of these tools, though, is hardly achieved, and security is an issue when sensitive data are to be displayed online.

We are currently assisting several irrigation districts in the Lower Rio Grande River, which have detailed information on water accounts and flows in the canals, with the objective to improve the efficiency of daily water management. In this paper we present

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the studies of two districts that begun in 2009 and 2010. GIS was integrated to daily water accounting information and to real time water flow monitoring, and linked to the district website. This paper focuses on identifying problems and recommendations, proposing changes, and evaluating the effects of adopted changes.

PROJECTS FEATURES

The projects were carried out in two irrigation districts in the Lower Rio Grande Valley: Brownsville Irrigation District (BID) and Cameron County Irrigation District No.2 (CCID2) (Fig. 1). We describe here the improvements made to the BID project, as compared to the finding by Bonaiti and Fipps (2010), and the new CCID2 project.

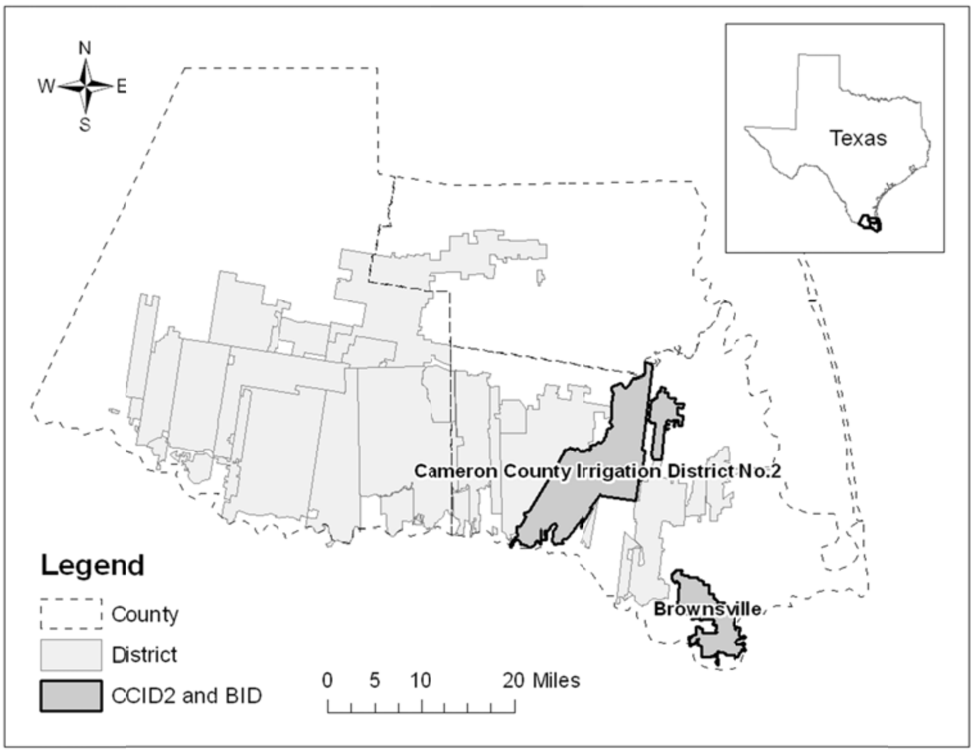


Figure 1. Cameron County Irrigation District No.2 (CCID2) and Brownsville Irrigation District (BID)

Brownsville Irrigation District (BID)

The improvements made to the BID project, which started in 2009, were an updated list of recommendations, data transfer and storage, the improved access to water account data, and the use of periodic evaluations for estimating effects of the activity. Table 1 presents an updated list of the problems and recommended changes.

Table 1. Identified problems and recommended changes for BID (2011 update)

	Problems	Suggestions
Water account database	1. Multiple databases*	1. Need one unified database
	2. Obsolete database software*	2. Move to a new open source database
	3. Output data are in a proprietary format	3. A routine had to be added that converts output in a text file format every day. Convert other database files if needed
	4. Irrigated fields (Locations) are not considered. As a result, water orders acreage do not match water account acreage*	4. Add Locations
	5. Crop management data are not available	5. Add planting date, harvest date, and irrigation method
SCADA	6. There is no communication with the internal network. Connection is needed to directly retrieve data without using Internet	6. Connect the computer to the internal network
	7. Output data are in a proprietary format. Set up is not stable*	7. A routine had to be added that converts output in a text file format every 15 minutes. Add pump on/off information in the output data
GIS	8. Multiple databases*	8. Need one unified database
	9. The information is not up to date*	9. At least yearly update is needed
	10. Irrigated fields (Locations) are not mapped*	10. Add Locations (use the same code or name used in the water account database)
	11. Turnouts are not mapped	11. Add turnouts and command areas
	12. Maps are not properly drawn*	12. Add spatial references, snap beginning and ending points of canals and pipelines, add direction of flow to canals and pipelines, edit at scale equal or larger than 1:10,000
	13. Water account number in the database includes a prefix number. This can lead to errors in data processing*	13. Split water account number and prefix in two separate columns in the database table

*Primary problems

The transfer of data is made possible through the SshSendFile.msi protocol, installed in the computers hosting the SCADA unit and the water account database. It enables transfer of all output files through the Texas A&M University (TAMU) firewall. SCADA data are sent every 15 minutes, while water account data are sent daily. All data, including spatial data, are now stored in a SQL Server database. Links to spatial data are ensured using the ArcGIS Server software, version 10.0. GIS data are manually modified every time there is an update.

A new open source database was adopted by the district to manage the water accounts. Therefore, it has been necessary to re-establish the extraction, transfer, and elaboration of data. By adopting the new database, new information became also available, which can now be retrieved from the web applications.

An evaluation form was periodically distributed to the district personnel for feedback on the effectiveness of the product and on the potential for water and cost saving. Such suggestions will help with the development of new recommendations for further improvement.

Cameron County Irrigation District (CCID2)

A new project started in 2010 with CCID2, one of the biggest districts in the Lower Rio Grande Valley. The district provides municipal water for San Benito, Rio Hondo and East Rio Hondo Water Supply Corporation (WSC), American Electric Power/Central Power and Light Company (AEP/CPL), and over 57,000 acres of irrigated farmland. The delivery network includes about 20 miles of resacas[3], 100 miles of pipelines, 200 miles of open canals (mostly unlined), one pump on the Rio Grande, 15 lift pumps , and 10 automated gates (Fig. 2). The project included the following steps:

1. analysis of the current database management
2. list of identified problems and recommended changes
3. demonstrations on proposed improvements
4. set-up of a pilot project to improve data management and availability through the Internet

Database analysis and recommendations. We examined the district's internal computer network to ascertain if and how computers are interconnected, how data is stored, what software is used for data acquisition and management, and what level of training does district personnel receive on the use of computer systems and associated software. Data recorded at the district office were identified, along with storage and use details. We also determined what type of information district personnel considered the most useful and what improvements were desirable.

The pump on the Rio Grande River, and several gates (Rubicon technology) are equipped with remote terminal units (RTUs) for remote control. They are operated remotely with two SCADA units, which are installed on two separate personal computers (PC1 and PC2) disconnected from the internal network (Fig. 3). The first SCADA unit interrogates the river pump RTU for equipment status (whether pumps is on or off), flow rate, and cumulated flow. The second SCADA unit interrogates the Rubicon gates RTUs for upstream and downstream water level, gate opening, and water flow. This SCADA unit is also operated via the Internet by specialized district personnel using a laptop.

Water account information is stored and updated in the server using a Microsoft Windows Access database (Fig. 3). The district manages water orders by selling "water tickets," which specify detailed information such as date of purchase and delivery, amount of water ordered, name of landowner and grower, and crops grown. The GIS database is managed with a third PC (PC3) disconnected from the internal network.

[3] An area of river bed that is flooded in periods of high water; an artificial reservoir (Dictionary of American Regional English, 2011. [online] URL: http://dare.wisc.edu/?q=node/144)

A list of the problems and recommended changes were compiled for the district (Table 2). The primary problems were that SCADA outputs are in a proprietary format, information on crop management and delivered volumes is not complete, and GIS is not up to date (e.g. irrigated fields are not present).

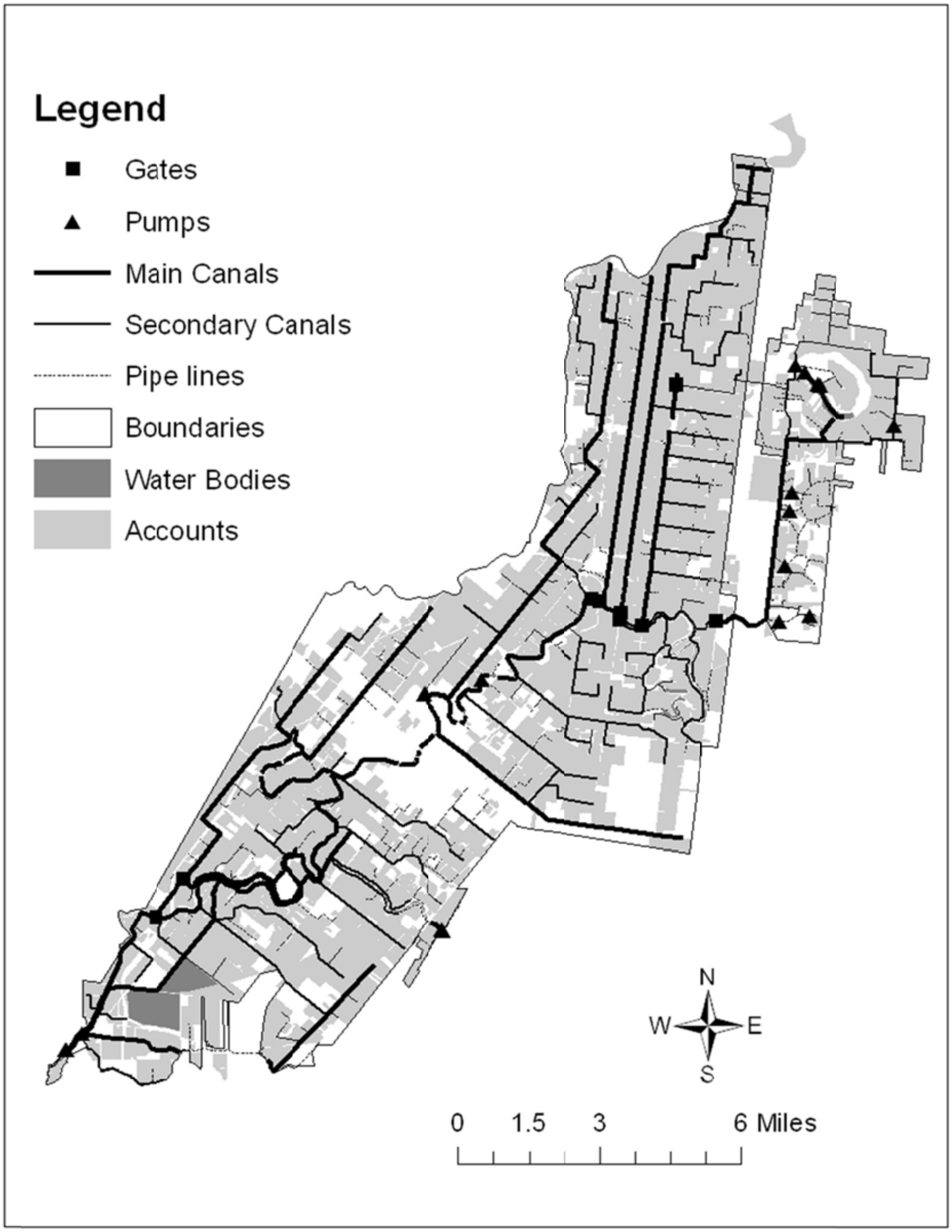


Figure 2. Delivery network and water accounts in the CCID2

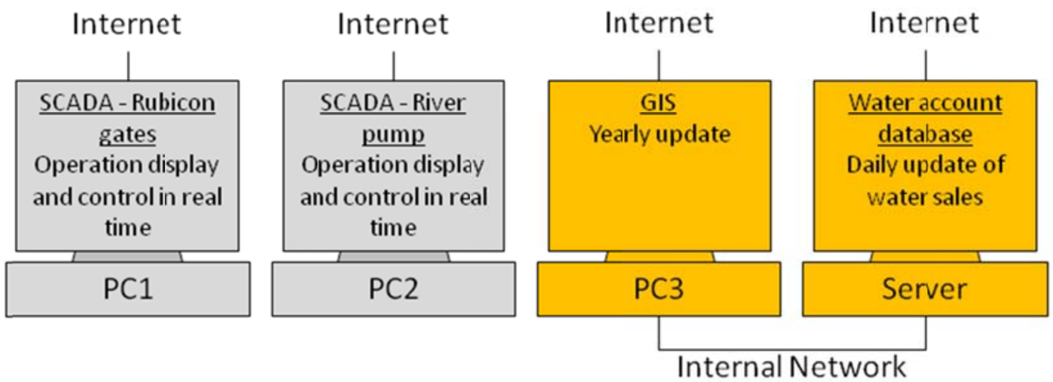


Figure 3. Schema of gates, pumps, and water orders database management
Communication with the internal network is highlighted

Table 2. Identified problems and recommended changes for CCID2

	Problems	Suggestions
Water account	1. Property ID # (PID) is not updated. As a result link to map might fail*	Update PID
	2. Some crop management data are not available	Add planting and harvest date
	3. Delivered volume is missing (only ordered)*	Measure/estimate delivered volumes
	4. Status and date wanted for PID are missing, and cannot be displayed on map*	Ask more detailed information on PID when selling water tickets
	5. Currently irrigated PID/account is not identified*	Monitor begin and end of irrigation
SCADA	6. There is no communication with the internal network. Connection is needed to directly retrieve data without using Internet	Connect the computer to the internal network
	7. Rubicon and Eagle Automation output data are in a proprietary format*	A routine had to be added that converts Rubicon output in a text file format every 15 minutes. Convert also Eagle Automation output data
	8. There is no information on currently operated canals and gates, other than at Rubicon gates (open/close, flow, etc.)	Connect other key locations for irrigation management to the SCADA system
GIS	9. The information is not up to date*	At least yearly update is needed
	10. Turnouts and command areas are not mapped*	Add turnouts and command areas
	11. Max capacity of gates and canals is not in database*	Add max capacity of gates and canals
	12. Maps are not properly drawn*	Add spatial references, snap beginning and ending points of canals and pipelines, add direction of flow to canals and pipelines, and edit at scale equal or larger than 1:10,000

*Primary problems

Web GIS Pilot Project. We set up a demonstration (Web GIS Pilot Project) to introduce the manager and district personnel to the possible use of the ESRI ArcGIS Server software (version 10.0) to integrate SCADA and water orders data, and post them online. The Web GIS Pilot Project is organized in the following steps: 1) ensuring correct data format and features, 2) transferring files in real time from the district computers to our server, 3) storing and processing received files and creating GIS projects, and 4) creating Web GIS applications for remote access.

A routine added by the Rubicon contractor in PC1 outputs and saves gates data in a CSV file format every 15 minutes. Data on PC2 have been not used due to unresolved problems with the contractor. A routine added by the IT consultant in the Server automatically extracts selected tables from the Access database as Excel spreadsheets every day. A procedure set up in collaboration with the district personnel ensures frequent updates of GIS features classes.

The SshSendFile.msi protocol, installed it on PC1, PC2, and the server, enables transfer of all output files through the TAMU firewall. Gate data are sent every 15 minutes, while water sales are sent daily.

All data, including spatial data, are stored in a SQL Server database. Links to spatial data are ensured using the ArcGIS Server software, version 10.0. GIS data are manually modified every time there is an update. Data are organized to be accessed, displayed and downloaded through the Internet according to the needs of the district manager and personnel (Fig. 4).

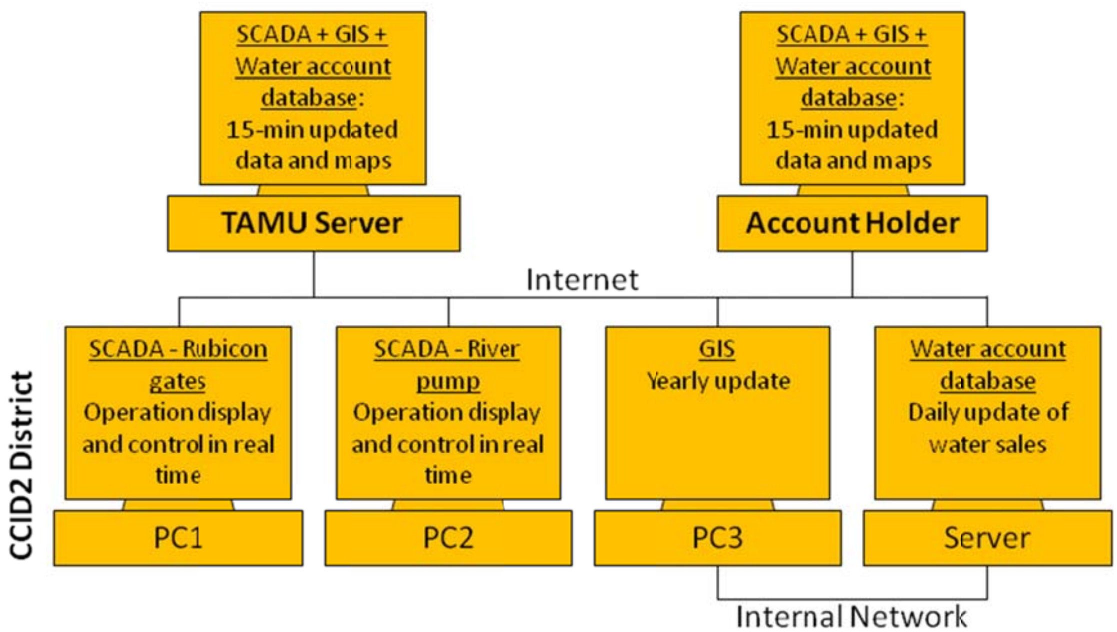


Figure 4. Database management in the Web GIS Pilot Project. Data and maps are shared through the Internet

Data access, display and download are set up differently for the growers/landowners than for district personnel, to better manage permissions and security issues. District personnel can access all data by means of a password protected web application, in which real time and historical data can be queried and downloaded as a spreadsheet and/or displayed on an interactive map. Alarms are set to alert on specific problems (e.g. water levels), and a static map is set up to show the most relevant information in real time, such as water flow, water levels, alarms, and pending water orders (Fig. 6-8). The grower and the landowner can open a dedicated interactive map (web application) on the district webpage. From the webpage, the grower/landowner can locate their fields and find related information on water tickets. Each query requires a password, which was mailed to the grower/landowner. Visualized information can also be printed. The map includes useful feature and images, such as delivery network, roads, district boundaries, and aerial photography (Fig. 9).

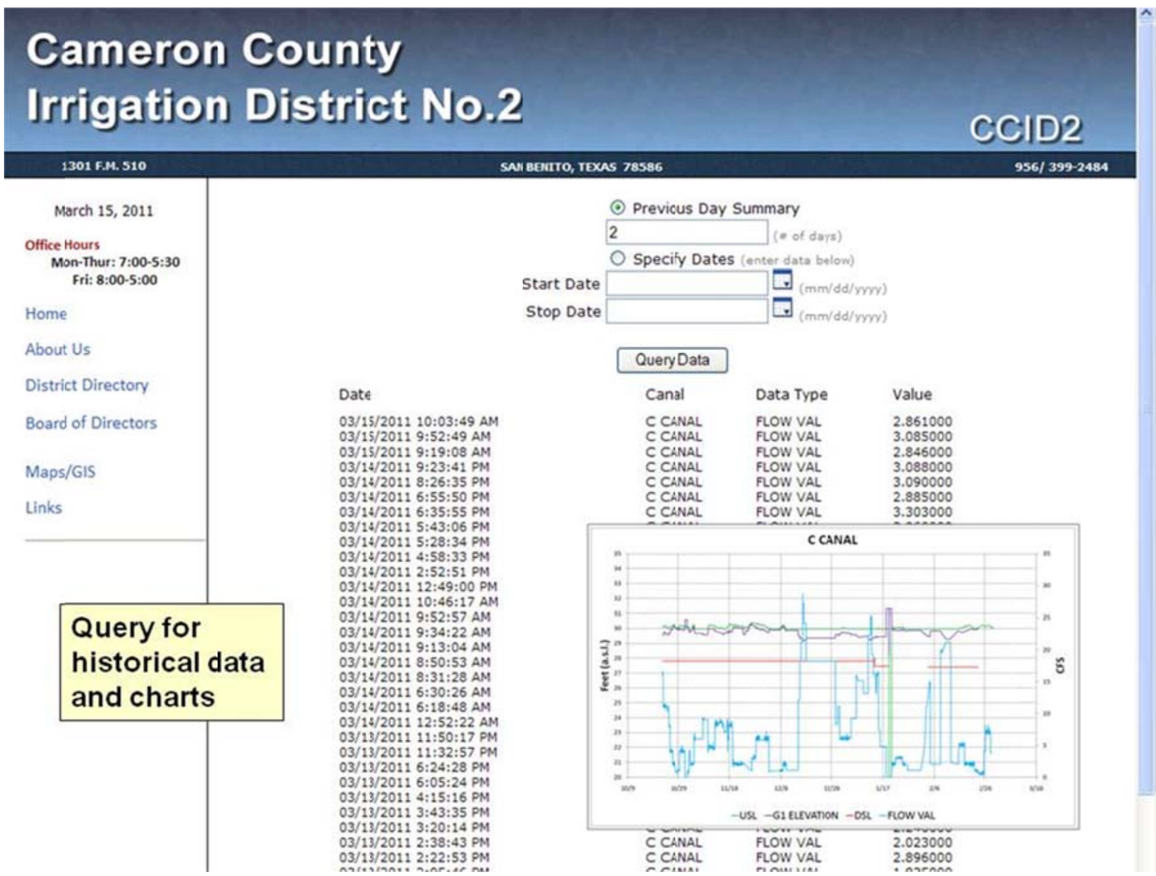


Figure 6. Historical data and charts on gates, downloaded by district personnel

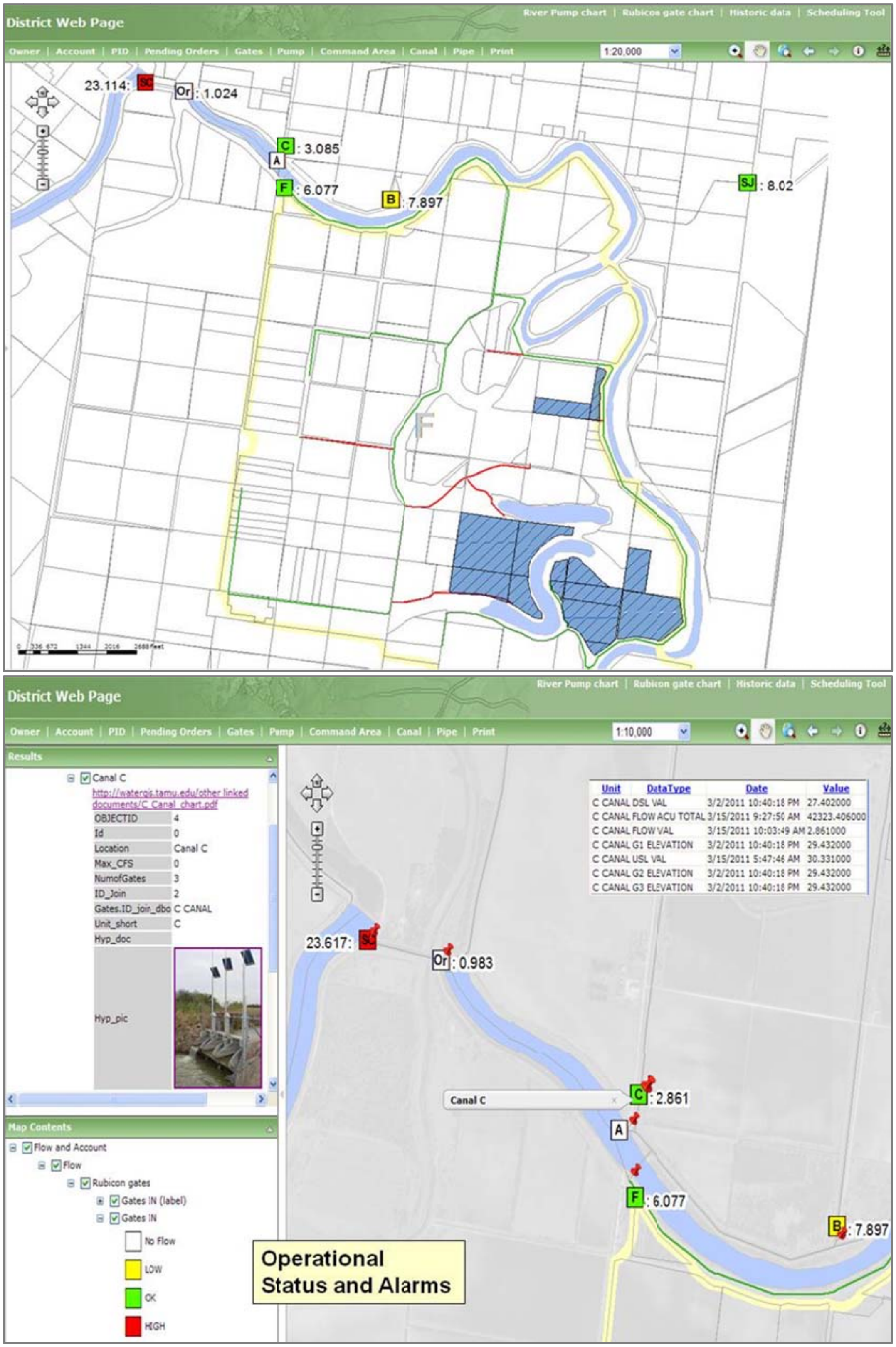


Figure 7. Interactive map accessed by district personnel. Top: Current water orders, network, gates alarms. Bottom: Detailed information on status of gates

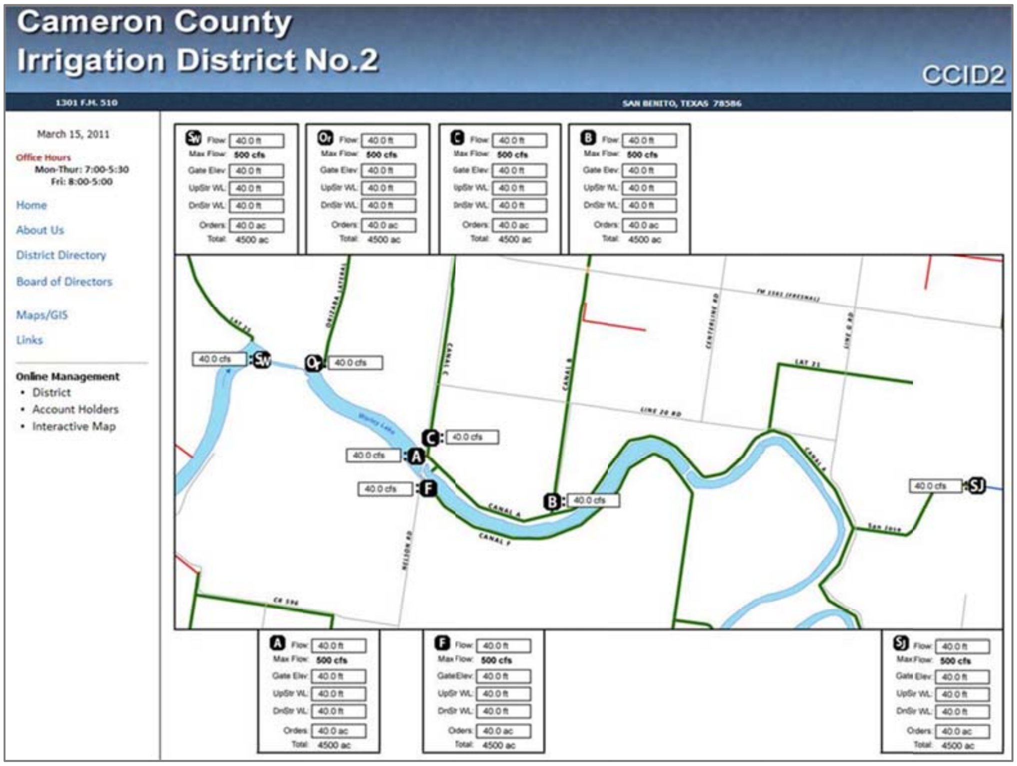
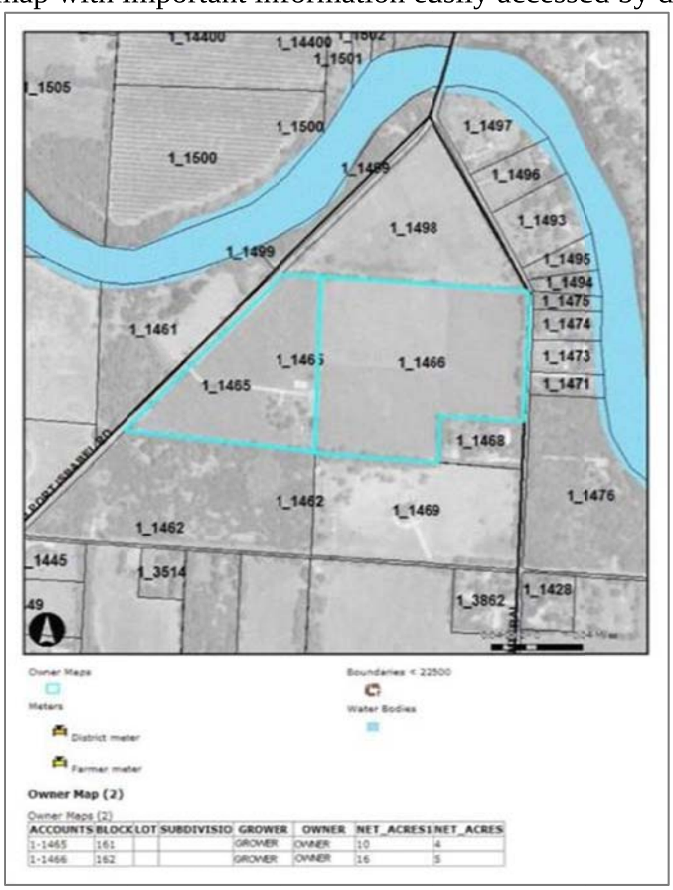


Figure 8. Static map with important information easily accessed by district personnel



ACCOUNTS	BLOCK	LOT	SUBDIVISIO	GROWER	OWNER	NET_ACRES1	NET_ACRES
1-1465	161			GROWER	OWNER	10	4
1-1466	162			GROWER	OWNER	16	5

Figure 9. The grower/landowner can identify land on map and print a report

ENCOUNTERED PROBLEMS AND EFFECTS OF INTRODUCED CHANGES

Problems and Solutions

Data management. The SCADA database was in a proprietary format and required the intervention of the contractor to be converted into a format that could be used by district personnel. The polling interval and method varied according to the contractor. The set-up of a routine creating output data every 15 minutes was a feasible solution for all contractors, and acceptable for the time step required by the district personnel. Water account databases were also in a proprietary format in some cases, requiring the same solution adopted for SCADA systems. In the case of CCID2 the database was a Microsoft Access database, which is a simple database to deal with. Also in this case, though, the extraction of selected data was a process not performed on a regular basis, which required some set-up time by the IT consultant. We preferred to let the consultant deal with the processing of the database, even if the data were available in accessible format. Over all this phase required long time, but in our opinion was a successful process.

The other problems related to data management were automatically transferring them to our server, and storing and connecting them to spatial data. The issue with the firewall protecting the TAMU server was solved by writing a specific code (SshSendFile.msi protocol), while the storage and management of data was all done using a SQL server database. Also the spatial data were converted to geodatabases and stored in the SQL database, and dynamic links were managed with the “join” operation within the ArcGIS projects.

Collaboration with contractors and consultants. The involvement of the contractors was needed because most of the time they were the only ones that could manipulate the data. Often they also were the only ones that knew exactly what data were available. Contractors sometime saw us as competitors, so cooperation was lacking at times. This problem was resolved through negotiations that involved all of the people, sometimes being very time consuming. In one case we didn’t reach agreement. Except for a few times, the district encouraged us to be involved with the contractors.

As mentioned above, we always involved the consultants when managing data within the district office. This involvement was beneficial not only in terms of knowledge and future collaboration, but also in terms of minimizing any impediment to the current organization of the system. For example, minor issues needing resolution included the set up of additional users and passwords, and the choice of the best time of the day to extract and transfer files in case that the computer would be switched off at night.

Identification of district needs and best solutions. A challenging activity within the project was to identify solutions that would suit the district needs. As the district was not familiar with the proposed technology we had to design the project based on our knowledge of the district, rather than on a specific request. Among other activities, we organized some GIS classes to ensure basic skills, and workshops to demonstrate and discuss the features of the project. As a result we gained good understanding of the district activities, personnel skills, and potential for improvements.

Security. One of the recurring requests by the district was a security system that would ensure protection to sensitive data, such as landowner names, addresses, water and money balances, and meter readings. A simple password system was enough for most data, and this was possible also for the ArcGIS Web applications. In some cases, such as when enabling the user to access money and water balances, we introduced an Hypertext Transfer Protocol Secure (HTTPS) to provide encrypted communication and secure identification.

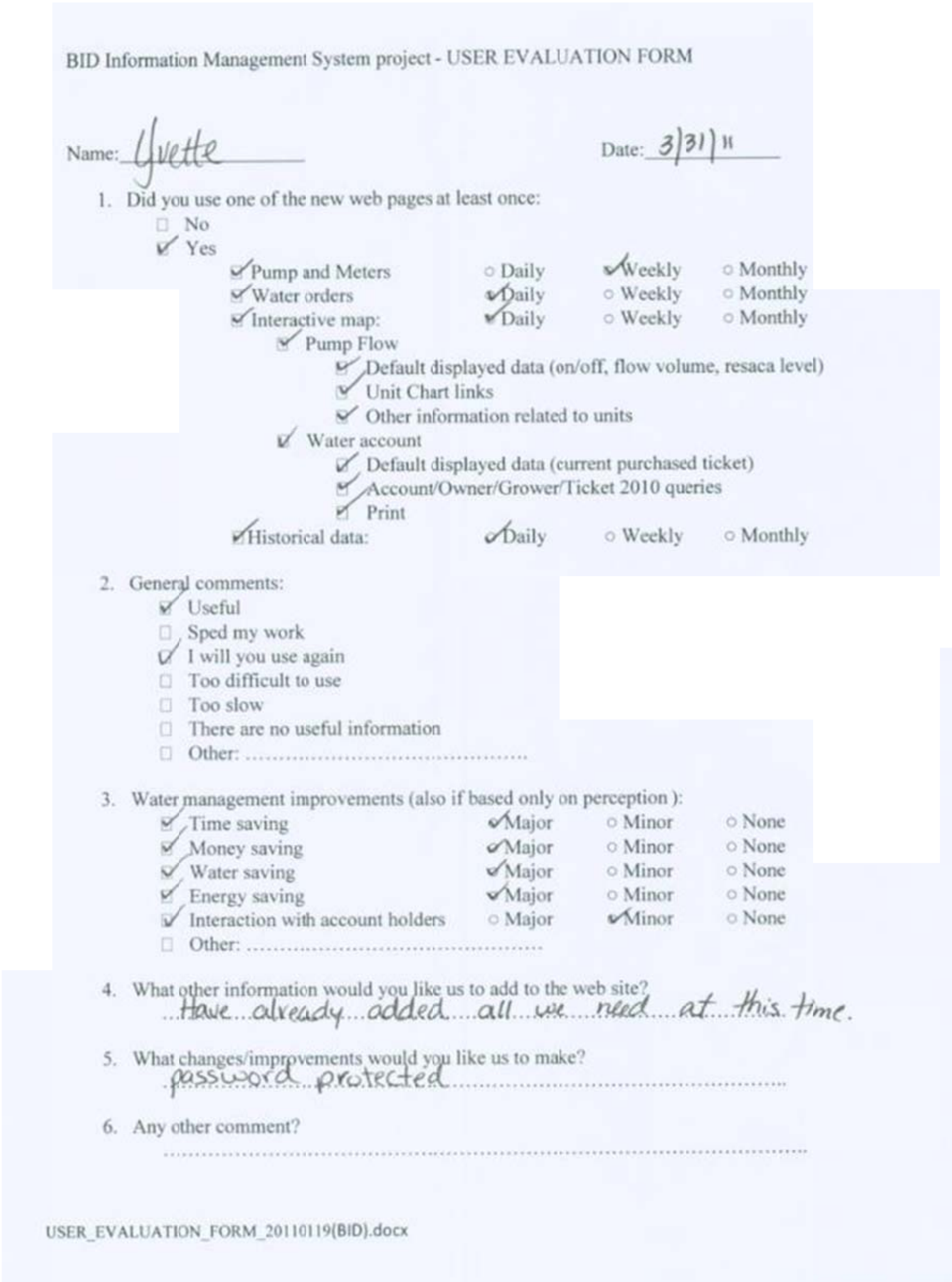
Data validation. Finally, another issue that we encountered was the management of un-validated data, still present in the database because the district typically used SCADA data only as real time source of information. Considering the importance given to the historical data in our project, we set up some simple automatic strategies to overcome most of the common errors, such as setting of routines to delete data when outside a minimum or maximum threshold.

Effects on district activity

Our activity produced some effects that looked promising for the improvement of the water management efficiency. A direct effect of the project was the district's newly adopted work strategies. Probably one of the most interesting feature was the ability of the account holders to read their own flow meters at the beginning and at the end the irrigation. District personnel evaluated the process periodically through an evaluation form process (Fig. 10). From these initial forms there was a consistent perception that the changes introduced could save water and costs.

Another type of effect was the compliance to our recommendations for improvement, in addition to the changes required to develop the activity. For example, the district moved from an old-fashioned proprietary water account database to an open source database. Many other changes are being introduced, such as introducing other crop management data (e.g. date of planting and irrigation method), updating of water account information daily, and bringing GIS up to date. Overall, we observed an active response to our suggestions, and the development of new ideas. We therefore proposed an extended collaboration for a second phase with new goals based on such ideas.

The promising results encouraged both districts to engage in funding the second phase of the project. The results also moved other districts to seek collaboration with us in order to set up similar systems. These districts found out about the program in various ways, such as workshops, word of mouth, etc.



BID Information Management System project - USER EVALUATION FORM

Name: Yvette   Date: 3/31/11

1. Did you use one of the new web pages at least once:
   - ☐ No
   - ☑ Yes
     - ☑ Pump and Meters   ○ Daily   ✓Weekly   ○ Monthly
     - ☑ Water orders   ✓Daily   ○ Weekly   ○ Monthly
     - ☑ Interactive map: ✓Daily   ○ Weekly   ○ Monthly
       - ☑ Pump Flow
         - ☑ Default displayed data (on/off, flow volume, resaca level)
         - ☑ Unit Chart links
         - ☑ Other information related to units
       - ☑ Water account
         - ☑ Default displayed data (current purchased ticket)
         - ☑ Account/Owner/Grower/Ticket 2010 queries
         - ☑ Print
     - ☑ Historical data: ✓Daily   ○ Weekly   ○ Monthly

2. General comments:
   - ☑ Useful
   - ☐ Sped my work
   - ☑ I will you use again
   - ☐ Too difficult to use
   - ☐ Too slow
   - ☐ There are no useful information
   - ☐ Other: ....

3. Water management improvements (also if based only on perception):
   - ☑ Time saving   ✓Major   ○ Minor   ○ None
   - ☑ Money saving   ✓Major   ○ Minor   ○ None
   - ☑ Water saving   ✓Major   ○ Minor   ○ None
   - ☑ Energy saving   ✓Major   ○ Minor   ○ None
   - ☑ Interaction with account holders   ○ Major   ✓Minor   ○ None
   - ☐ Other: ....

4. What other information would you like us to add to the web site?
   ...Have already added all we need at this time.

5. What changes/improvements would you like us to make?
   password protected...

6. Any other comment?
   ....

USER_EVALUATION_FORM_20110119(BID).docx

Figure 10. Evaluation form for district personnel, completed periodically

CONCLUSIONS

The project was developed in districts that were already feeling the urgency to upgrade their technologies, including GIS. Specific interests were to make best use of the large amount of available data, to adopt web applications, and to enable customers to access their data through the Internet.

Despite the efforts and will, these changes required a long time to be fully implemented due to a number of issues, such as identifying district needs, accurately designing the project, integrating the non optimal existing data, securing sensitive data, and involving contractors and consultants. Referring to contracts, they should be specific in non-propriety software in that any consultant should be able to modify in the future, and district personnel should be able to extract all data they need at any time. Nevertheless, collaboration with contractors resulted beneficial for the sound implementation of the project.

The activity produced some effects that looked promising for improved water management efficiency. The districts adopted most of the new proposed strategies, promptly complied with many recommendations, started suggesting further steps, and directly began to participate in the project implementation expenses. Finally, other districts requested our collaboration to set up similar projects.

There was an overall feeling from the districts that the adopted changes would help save water and costs, and this was assessed by means of periodical qualitative evaluations. Nevertheless, there is a need to quantitatively estimate such benefits. Water balances and reliable historical data might help to make these assessments in the future. An initial understanding of such benefits might be obtained with a description of improved services provided to growers (e.g. availability of flow meter readings on line reduces the number of calls to the canal rider).

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Fipps G., Leigh E. 1998. GIS-Based Management System for Irrigation Districts: Implementation of a District Management System in the Lower Rio Grande Valley of Texas. Proceedings of the 14th Technical Conference, Phoenix, Arizona, June 3-6, 1998: US Committee on Irrigation and Drainage

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

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

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 velocity sensor is installed and a relationship is developed between the velocity of the

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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. Thus small channels and irrigation turnouts 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).

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

A preliminary flow comparison study was conducted at the Irrigation Training and Research Center (ITRC) at the California Polytechnic State University, San Luis Obispo (Cal Poly). Figure 1 displays an aerial photo of the testing facility. The testing facility has a 280 ft long hydraulic flume with dimensions of 4.0 ft by 4.0 ft. A variable speed pump, capable of delivering up to 30 cubic feet per second (cfs), delivers water through a pipeline to a buffer pond at the upstream end of the flume. A magnetic meter (magmeter) is located in the pipeline, with large air vents located upstream of the magnetic meter. Because a constant flow rate was desired, the pump was set at a constant speed and the water passed into and out of the buffer pond with no change in any of the downstream control structures over time. Measurements were taken after the flow rate stabilized in the flume test section, typically after 30 minutes. Water depths in the flume were controlled by flashboards or gates at the downstream end of the flume for the three tests presented here; water level was varied for each flow rate.

Figure 1. California Polytechnic State University
Irrigation and Training and Research Center

Reference measurements were made using a McCrometer® UltraMag model #UM06-30, 76 cm (30 in) meter (magmeter), which samples data multiple times per second and computes the average for a 2 second period. The magmeter's data is output using the meter's standard 4-20ma signal converter. A Control MicroSystems SCADAPack32 was used to convert the analog data to a digital number that was recorded every 2 seconds. The SonTek IQ was installed approximately 180 ft from the inlet of the flume in order to avoid turbulence and to allow flow to homogenize. The SonTek IQ was installed in the center of the flume at bottom of the flume using two 5/16 in stainless steel screws with the power and communications cable routed downstream. Figure 2 displays a picture of the SonTek IQ installation at ITRC.

Figure 2. SonTek IQ installation at ITRC flume

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.

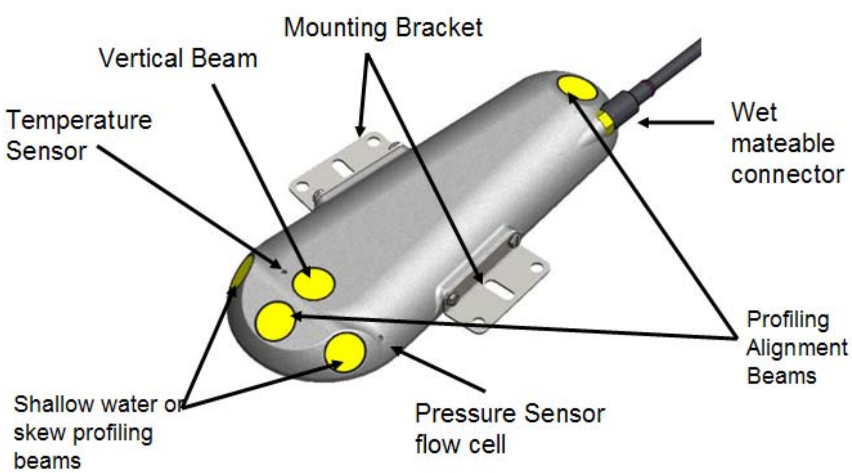

Figure 3. Features of the SonTek IQ

Figure 4 presents the 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, was 0.09 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.

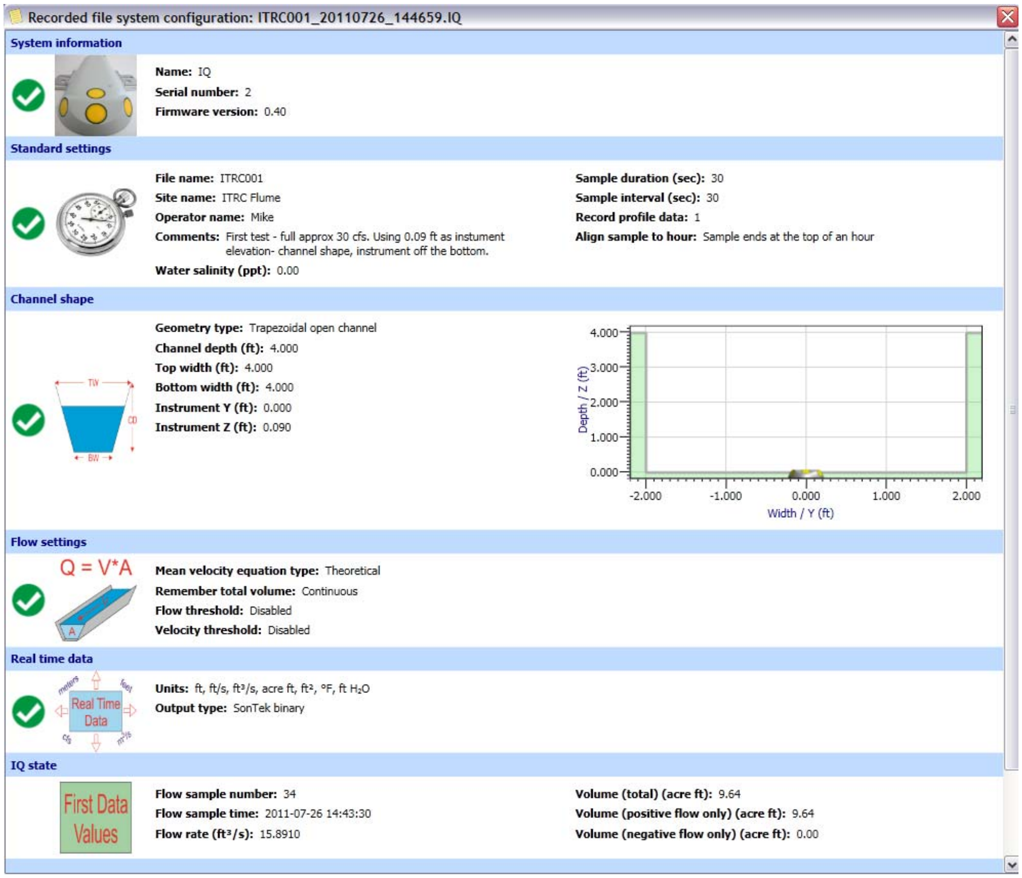

Figure 4. SonTek IQ configuration for ITRC testing

RESULTS

The results from three tests at the site are presented in Figures 5through 7. The blue line displays a trace for the flow measured by the magmeter, while the red line represents data from the IQ. Because the flow meters are not installed in the same place, the pumping rate and hydraulic head were held constant throughout the tests, and the flow rates were allowed to stabilize for 30 minutes in order to make data comparisons and the pumping rate. All tests were performed for approximately 30 minutes.

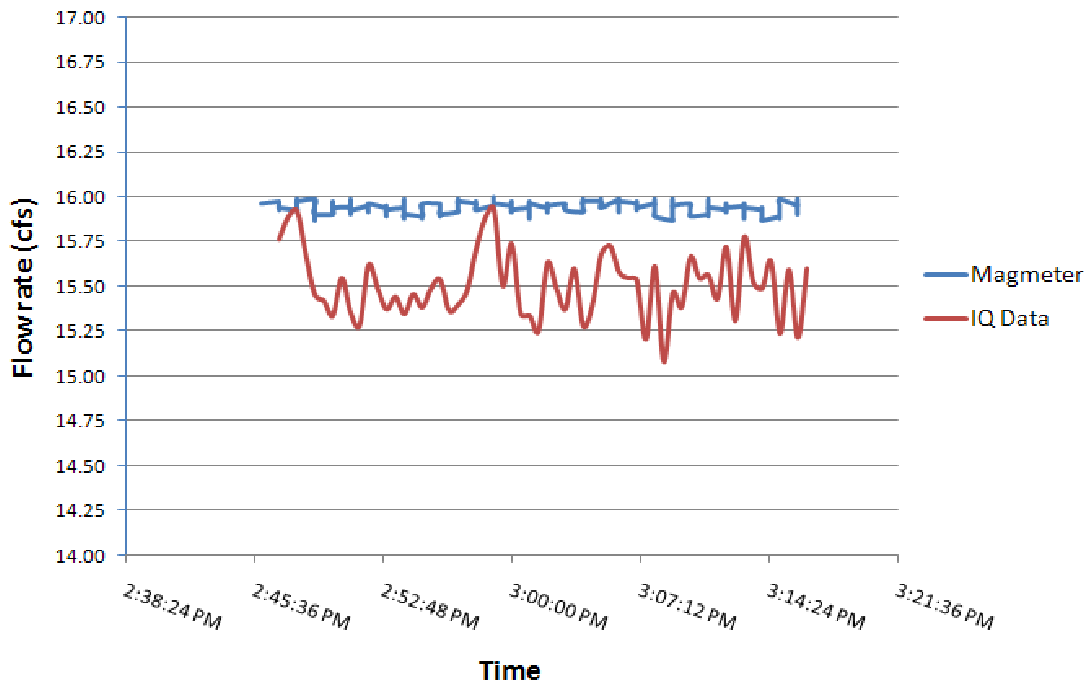

Figure 5. Flow data comparison at a reference flow of 15.94 cfs

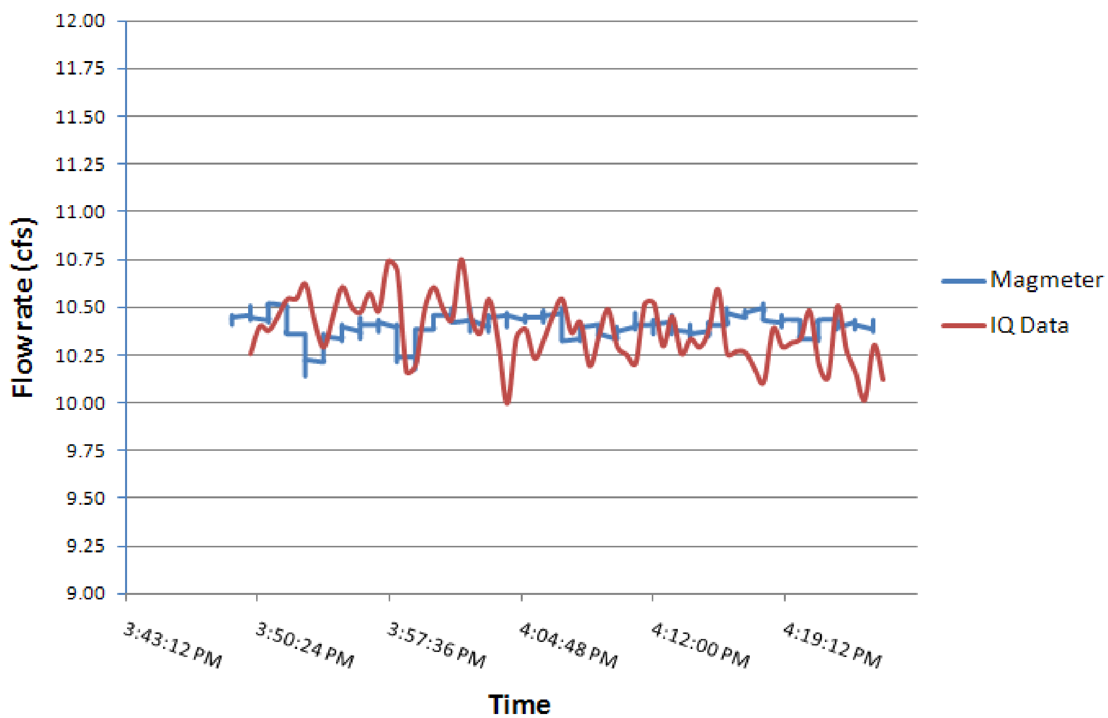

Figure 6. Flow data comparison at a reference flow of 10.42 cfs

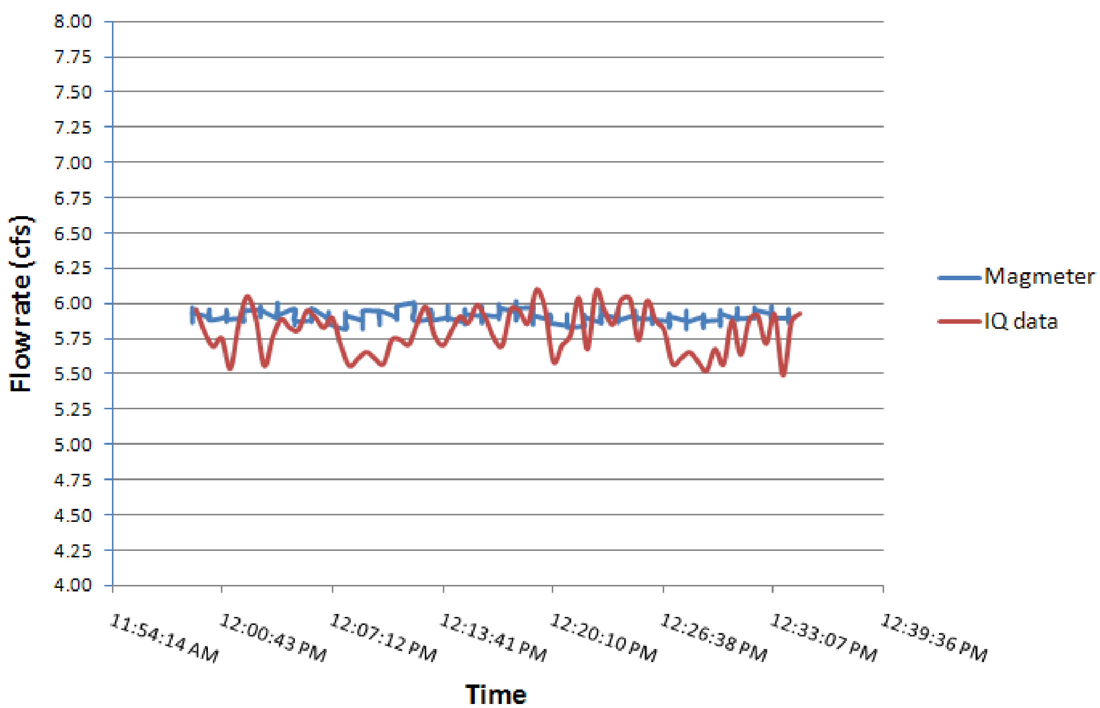

Figure 7. Flow data comparison at a reference flow of 5.80 cfs

Table 2 summarizes the results from the flow testing. The simple data analysis compares flow rate from the magmeter and SonTek IQ. In general, there is good agreement between technologies with the average difference of -1.68% for flow rate for the range of flow rates that were evealuated.

Table 2. Summary of the flow data comparing Magmeter and SonTek IQ

	Magmeter (cfs)	SOnTek IQ (cfs)	% Diff. Flow Rate (cfs)
Test 1	15.94	15.51	-2.69%
Test 2	10.42	10.38	-0.36%
Test 3	5.92	5.80	-2.00%

Over the period of the tests, the SonTek IQ collects additional data at the site. Table 3 presents average values for flow (cfs), velocity (ft/s) and stage (ft).

Table 3. Summary of average values collected by SonTek IQ

	Flow Rate(cfs)	Velocity (ft/s)	Stage (ft)
Test 1	15.51	1.67	2.32
Test 2	10.38	1.80	1.43
Test 3	5.80	0.84	1.73

CONCLUSIONS

Based on these preliminary tests, the SonTek IQ compares on average 1.68% lower than the reference measurement done using a magmeter. Graph indicate that the variability of the data from the SonTek IQ is greater than the magmeter, however the measurement devices are installed in two different environments – the magmeter in a pipe and the SonTek IQ in an open channel. The open channel environment for measuring flow is much more complex as flow patterns or velocity fields can be highly variable, where as in pipe conditions flow lines are streamlined and thus easier to measure. For accurate flow monitoring in open channels, it is necessary to sample a large portion of the water column as flow can be distributed unevenly, thus the SonTek IQ measures velocity horizontally and vertically by using the along axis beams as well as the skew beams. The SonTek IQ configuration and the corresponding algorithms have been specifically designed using data from agricultural canals to more accurately represent flow in open channel.

Preliminary results are encouraging when considering the low flow ranges evaluated (5.8 through 15.5 cfs) as well as velocities (0.84 through 1.80 ft/s) and stage (1.43 ft through 2.32 ft), however additional tests should be conducted to verify the performance of the instrument in a wider range of flow conditions. 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.

FLOW MEAUREMENT USING ACOUSTIC DOPPLER CURRENT PROFILERS ON AN IRRIGATION CANAL

Hening Huang[1]

ABSTRACT

This paper presents the field test results of two acoustic Doppler current profilers (ADCP) on an irrigation canal in Angoori Barrage, India. The first ADCP was a 2 mHz StreamPro ADCP, a portable flow measurement system. The second ADCP was a 1200 kHz ChannelMaster horizontal ADCP (H-ADCP), a fixed flow and water level measurement sensor. A total of eight transects of StreamPro ADCP flow measurements were conducted under a steady flow condition during the field test. The coefficient of variation (CV) for the eight flow measurements was only 1.34%. Concurrently with the StreamPro ADCP flow measurements, the ChannelMaster H-ADCP measured flow in real-time for about three hours. The flow measured by the StreamPro ADCP and that by the ChannelMaster H-ADCP agreed very well, within 2 %. It is important to note that the two ADCPs are different in operation, and purely independent. The results indicated that both StreamPro ADCP and ChannelMaster H-ADCP provided accurate flow measurements on the irrigation canal.

INTRODUCTION

An acoustic Doppler current profiler (ADCP) is a revolutionary tool for measuring open channel flows. Although ADCPs, introduced in early 1980's, are widely used in natural rivers and streams all around the world nowadays (e.g., Oberg et al. 2005, Simpson 2001), their use in irrigation canals are still relatively new and limited.

In order to examine the feasibility of ADCPs for measuring flows in irrigation canals, we conducted a field test in Angoori Barrage, India on December 16, 2004. Two types of ADCPs were tested. The first ADCP was a StreamPro ADCP (see the photo on the right). A StreamPro ADCP is a portable flow measurement system. It is specially designed for shallow cannels and can be used to calibrate other flow measurement devices such as weirs and flumes. A StreamPro ADCP includes an acoustic transducer head, an electronic housing, a small float, a pocket PC, operation software, and Bluetooth wireless communication. A StreamPro ADCP runs at an acoustic frequency of 2 mHz. It allows up to 30 velocity measurement cells (the user can set up the number of cells) with cell sizes ranging from 2 to 20 cm. The velocity profiling range is from 0.2 to 6 m. A StreamPro ADCP is usually tethered to a pulley system or a cableway. When making a transect across a canal, a StreamPro ADCP collects data for water depth, float velocity, and water velocity along its track. Flow is

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calculated using these data by the StreamPro operation software as soon as the transect is completed.

The second ADCP was a 1200 kHz ChannelMaster horizontal ADCP (H-ADCP, see the photo on the right). A ChannelMaster H-ADCP is a fixed flow and water level measurement sensor. It is specially designed for on-line monitoring of open channel flows and can be easily integrated into a SCADA system or a telemetry system. An advantage of the H-ADCP over weirs or flumes is it does not result in a head loss. A ChannelMaster H-ADCP is usually mounted on a channel bank or pier with two acoustic beams looking horizontally. It allows up to 128 velocity measurement cells. In addition to its two horizontal beams for horizontal velocity profiling, it has a third, vertical beam for water level (stage) measurement. A ChannelMaster H-ADCP also has a built-in tilt sensor to measure pitch and roll. The 1200 kHz ChannelMaster H-ADCP has a maximum profiling range of 20 m. ChannelMaster H-ADCPs are also available at 600 and 300 kHz, which have a maximum profiling range of 90 and 300 m respectively.

Note that a ChannelMaster H-ADCP does not measure flow directly. A flow calculation method must be employed. Two methods are available. One is a numerical model (Wang and Huang 2005) and the other is the so-called index velocity method, i.e., a calibration method. Details on the index-velocity method can be found in Huang (2010).

THE TEST SITE

The test site was at an irrigation canal located about 100 m downstream of a gate structure (Figures 1). The canal was constructed with a concrete block lining. Its bottom width is 7.62 m and the slope is 1:1.5. The canal flow is controlled by the gate structure. Its normal flow rate is about 22 m^3/s when the water depth is about 2 m.

Figure 1. View downstream from the gate structure. The test site was about 50 m downstream the curve.

The StreamPro ADCP was tethered to a pulley system. The ChannelMaster H-ADCP was mounted on a mounting plate that can slide into the water. Figure 2 shows the StreamPro ADCP tethered to the pulley system and the ChannelMaster H-ADCP being deployed onto the right bank.

Figure 2. The StreamPro ADCP was tethered to a pulley system at the test site. The ChannelMaster H-ADCP was being deployed onto the right bank.

DATA AND ANALYSIS

StreamPro ADCP Measurements

The StreamPro ADCP was configured using its operation software running on an iPAQ pocket PC. The parameter settings are: transducer depth=5 cm, cell size=10 cm, and number of cells=20.

A total of 8 transects of StreamPro ADCP measurements were conducted between 10:00 and 12:30. Each transact took about 2 to 3 min to complete.

Figure 3 shows a screenshot from the WinRiver software when playing back the StreamPro data file for Transect 7. The top plot shows the velocity magnitude contour as well as water depth along the float track. It can be seen from the contour plot that the velocity was high in the region near the left bank of the canal. This is due to the fact that the main flow was skewed to the left bank because of the curve (near 90 degree) about 50 m upstream.

The bottom plot on the screenshot shows the float track (red line) as well as depth-averaged velocity vector (blue sticks) along the track. The StreamPro ADCP outputs the velocity vectors (and other data) at 1 Hz, i.e., one vector per second. It should be noted that the velocity direction and float track direction are relative to the ADCP instrument coordinate, not to the earth coordinate. This is because StreamPro ADCP has no compass in it. A compass is not needed for flow measurement when the float velocity is obtained from the ADCP's bottom tracking.

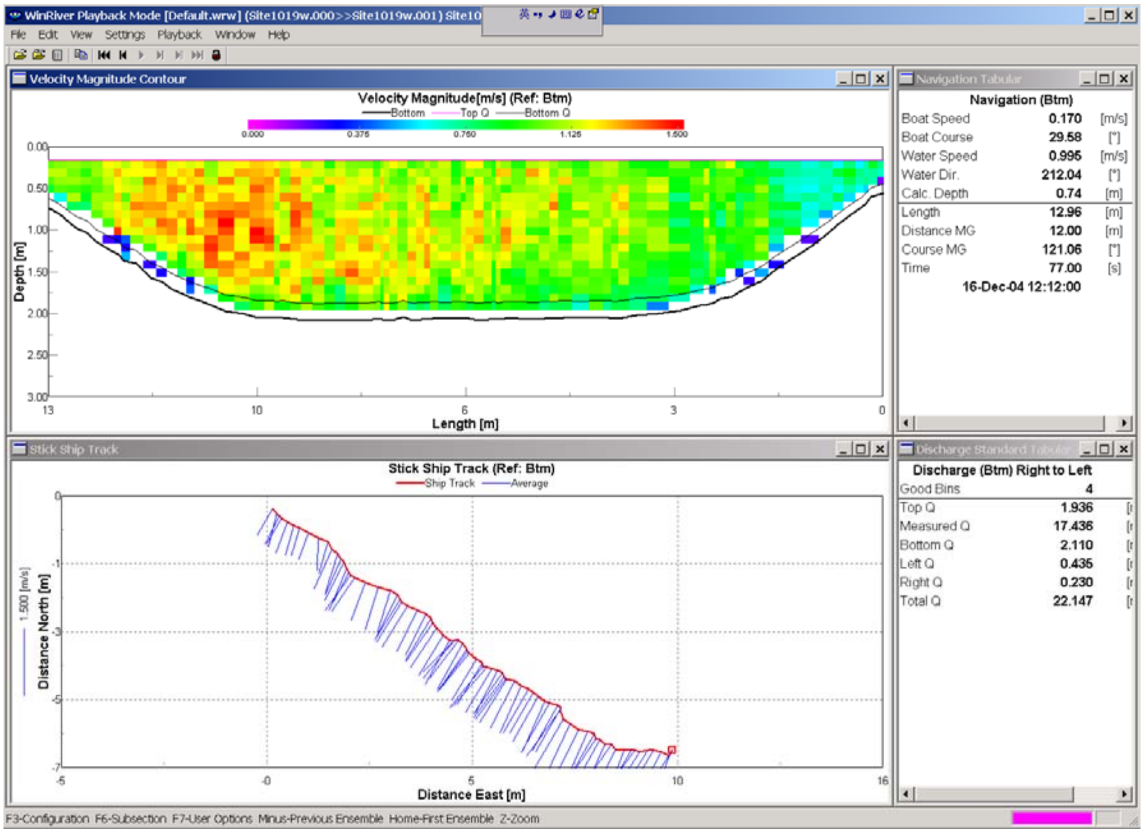

Figure 3. Screenshot of WinRiver when playing back the Transect 7 StreamPro data file

Table 1 shows the StreamPro ADCP measured flow from the eight transects. Some statistics of the flow data set are obtained as follows: mean = 21.894 m^3/s, standard deviation = 0.294 m^3/s, and coefficient of variation (CV) = 1.34%. The flow was nearly steady and about 22 m^3/s between 9:45 and 12:30 measured at the gate structure. The results indicate that the StreamPro ADCP provides repeatable and accurate flow measurements.

Table 1 StreamPro ADCP measured flow

Transect	Start Time	End Time	Duration	Q [m^3/s]
1	10:23:13	10:26:00	0:02:47	21.984
2	10:43:51	10:46:27	0:02:36	21.752
3	10:47:06	10:50:07	0:03:01	21.928
4	10:51:32	10:53:58	0:02:26	21.904
5	11:58:11	12:00:18	0:02:07	21.709
6	12:01:37	12:03:43	0:02:06	22.353
7	12:10:29	12:12:00	0:01:31	22.147
8	12:17:53	12:19:36	0:01:43	21.376

ChannelMaster H-ADCP Measurements

The ChannelMaster H-ADCP was configured using its operation software running on a PC. The parameter settings are: cell size=0.5 m, number of cells=30, blank distance=0.25 m, averaging interval=3 or 9 s, and sampling interval=4 or 10 s.

The ChannelMaster H-ADCP was initially put into the water around 9:45 and mounted at the right bank at an elevation of 1.55 m above the canal bottom. It was pulled out of the water around 11:10. It was deployed again shortly, mounted at an elevation of 1.52 m above the canal bottom and ran until around 13:15. During the second deployment, the H-ADCP was stopped two times to change settings.

The H-ADCP data were displayed and reviewed in real-time as well as in data play back through the H-ADCP operation software. The H-ADCP software employs a numerical model developed by Wang and Huang (2005) to calculate flow in real-time as well as in data play back.

Comparison

Figure 4 shows the time series data (100 s moving averaging) for the ChannelMaster H-ADCP measured flow (blue lines) and the StreamPro ADCP measured flow (red dots). Note that the flow was nearly steady and about 22 m^3/s between 9:45 and 12:30. But it was adjusted to lower flows between 12:30 to 13:00. However, no StreamPro ADCP measurements were made during the lower flow period.

It can be seen from Figure 4 that the flow measured by the ChannelMaster H-ADCP and that by the StreamPro ADCP agrees well, within 2 %. It is important to note that the two ADCPs are different in operation, and purely independent. The results indicated that both the StreamPro ADCP and ChannelMaster H-ADCP provided accurate flow measurements on the irrigation canal.

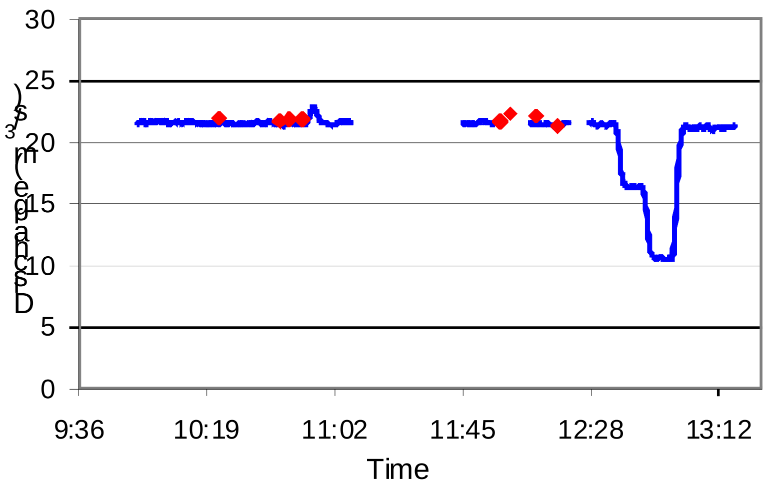

Figure 4. Time series data for the ChannelMaster H-ADCP measured flow (blue lines) and the StreamPro ADCP measured flow (red dots)

CONCLUSION

The field test results show that both of the StreamPro ADCP and the ChannelMaster H-ADCP provided repeatable and accurate flow measurements on the irrigation canal. A StreamPro ADCP can be used to calibrate other flow measurement devices such as weirs and flumes. A ChannelMaster H-ADCP can be used for on-line flow monitoring of open channels. It can be easily integrated into a SCADA system or a telemetry system. An advantage of the H-ADCP over weirs and flumes is it does not result in a head loss. ADCPs are promising tools for measuring flows in irrigation canals.

ACKNOWLEDGEMENTS

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SAVE WATER SAVE ENERGY SUCCESS STORY OF SCIENTIFIC IRRIGATION SCHEDULING

Jac le Roux[1]
Mike Omeg[2]

ABSTRACT

Starting in 2010, the United States Department of Agriculture (USDA) – Natural Resources Conservation Service (NRCS) secured funding and initiated a three year program bringing together the NRCS, Bonneville Power Administration (BPA), The Dalles Irrigation District (TDID), and cherry growers in The Dalles, Oregon to employ Scientific Irrigation Scheduling (SIS) to save water and energy.

34 growers enrolled in the program, covering 3,100 acres of irrigated cherry orchards. In the first year, the project produced an estimated energy saving of 969,215 kilowatt hours (kWh), or 312 kWh per acre, and water saving of 610 acre-feet (198,769,000 gallons) or $38,768 of electricity at the low unit cost of $0.04 per kWh.

The technology employed for SIS was a combination of the web based irrigation scheduling software called ProbeSchdule (www.probeschedule.com) , neutron moisture probes, and electronic soil moisture sensors (supplied by AgsysNorthwest) that reported soil moisture status to the website every 6 hours via a radio telemetry Irrinet LLC specializes in soil moisture monitoring and irrigation scheduling and was contracted to manage all data, supply irrigation schedules, train growers in the use of the software and generate year end reports. The software is designed for ease of use, and it took on average 1.5 hours of training for growers to understand and use the system.

This program has shown to be effective as demonstrated by this project. It could be implemented at various locations and save up to 20% in irrigation water use.

INTRODUCTION AND BACKGROUND

TDID had more than 200 aging flow meters in the district that were in need of replacement. Rather than replacing them with similar mechanical flow meters that have to be monitored in the field to get the current flow rate and cumulative volume per grower, the suggestion came to replace them with flow meters fitted with radio telemetry and have the flow rate and cumulative flow reported to the office. Expanding the idea to include soil moisture sensors and tapping into the $6.00 per acre energy rebate offered by BPA gave birth to the Save Water Save Energy Project. NRCS secured additional funding through their Cooperative Conservation Partnership Initiative (CCPI) to help pay for the hardware.

The radio telemetry was linked into the Integrated Fruit Production Network (IFPnet) already in operation in The Dalles. This helped to keep the over head cost of

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telemetry to a minimum. (It is worth mentioning that for a similar project in central Oregon, where no radio network was available, satellite telemetry was used with great success).

Participating growers had both electronic sensors and access tubes for neutron probe installed in orchard blocks at a density of roughly 1 site per 10 acres. Site selection was based on the variation in irrigation system, soil type, cultivar, and tree age.

Water savings were achieved by knowing the status of the soil moisture and irrigating on demand rather than by the calendar. Detailed soil moisture data are used in the ProbeSchedule software to analyze the effectiveness of irrigation sets and to calculate the optimal irrigation set size. The irrigation schedule provided by the software indicates when and how much to irrigate.

EQUIPMENT

Several pieces of equipment were used for SIS, namely neutron probes, software, weather stations, and electronic soil moisture sensors with telemetry.

Neutron Moisture Probe

The neutron probe has distinguished itself as the most accurate way to field measure soil moisture content, and it is for this reason that it was selected as the primary soil moisture measuring tool for this project.

The neutron moisture probes employed were model 503DR Hydroprobe (Figure 1) (from Instrotek Inc, CA). The neutron probes were gravimetrically calibrated for the typical soil found in the project area to display total soil moisture content (not to be confused with plant accessible moisture) in inches of water per foot of soil.

Neutron probe readings were taken at each site once a week and logged on the neutron probe’s data logger (Figure 1). The information was downloaded to a personal computer and then uploaded to the website where it was posted in the data set at the appropriate date and time. This measured soil moisture content was further used to cross check the modelled water balance and to field calibrate the electronic soil moisture sensors, which displays soil moisture content in percentage on a scale of 0 to 100% rather than reflecting actual soil moisture content.

Two neutron probe access tubes were placed in each orchard block. These were placed in different tree rows to get information from different trees, sprinklers and, laterals. Probe readings were then taken in each tube at every 6 inch depth from 6 to 36 inches for a total of 12 readings. The information was then averaged per depth. The two tubes are expected to respond in a similar manner to wetting and drying. If not, the cause is investigated. The two tube system provides a level of security. If a single site is used, there is no way of knowing if it is not performing correctly and is slowly changing with respect to the rest of the block.

During the installation of the tubes, the soil is augured in 6 inch intervals where each interval is examined for texture and current soil moisture status (Figure 2). This information is used to make the initial full capacity setup in the software.

Figure 1. Neutron moisture probe on the left and the probe in use in the field on the right.

Figure 2. Every 6 inches of soil is examined for texture and soil moisture status.

SIS Software

The SIS software used for this study is called ProbeSchedule ®, which is internet based (www.probeschdule.com). The software makes use of several irrigation scheduling techniques to generate clear graphs of the soil moisture status and to generate an irrigation schedule.

To calculate a daily water balance or a "water balance model", the software uses real-time weather data, soil moisture holding capacity, plant growth stage, and rooted depth as well as inputs for irrigation and rain. Models of this nature could drift away from reality if not cross checked and corrected by an external, objective data source. That is the role of the neutron probe. The weekly soil moisture reading is super-imposed on the model and the modelled water balance is corrected to match the actual probe reading. This technique provides the feed back to refine the model to the point where the model is 95% accurate. At this level of accuracy, it is save to take a neutron probe reading just once a week and fill the rest of the week with modelling.

The ProbeSchedule software automatically incorporates reference evapotranspiration numbers (Eto) and daily rainfall, directly from a RSS enabled weather stations. *(RSS (Rich Site Summary) is a format for delivering regularly changing web content. Many news-related sites, weblogs and other online publishers syndicate their content as an* ***RSS Feed*** *to whoever wants it).*

The only input required from the grower is the number of hours irrigated. The software provides for 3 independent irrigation systems such as drip for fertigation, under-tree micro for frost control and keeping the work row green, and an over head sprinklers for cooling.

Data are displayed in a number of graphs showing soil moisture status over time and in depth (figure 3). The green line represents the field capacity of the root zone (the amount of water that the soil can hold against gravity). The red line represents the planned re-fill point and is defined as a percentage deficit from the field capacity. The re-fill point is not a single percentage; instead, it is varied throughout the season to achieve different objectives during the growing season. For instance, while the fruit is sizing, the refill would be set at 20% deficit to ensure no soil moisture stress and maximize fruit size. Then after harvest, the re-fill could be lowered to 40% deficit to slow down vegetative growth or even 50% deficit to stop further growth.

Soil moisture is used very effectively in wine grapes to regulate growth and control berry size. By allowing the soil moisture status to drop to 50% deficit, vegetated growth is stopped. Then, by irrigating small volumes, further vegetated growth is prevented while the leaves are kept green and the berries are kept small (Figure 4).

Optimizing irrigation water use, optimizes nutrient uptake and crop development while it eliminates deep drainage and leaves more water in stream.

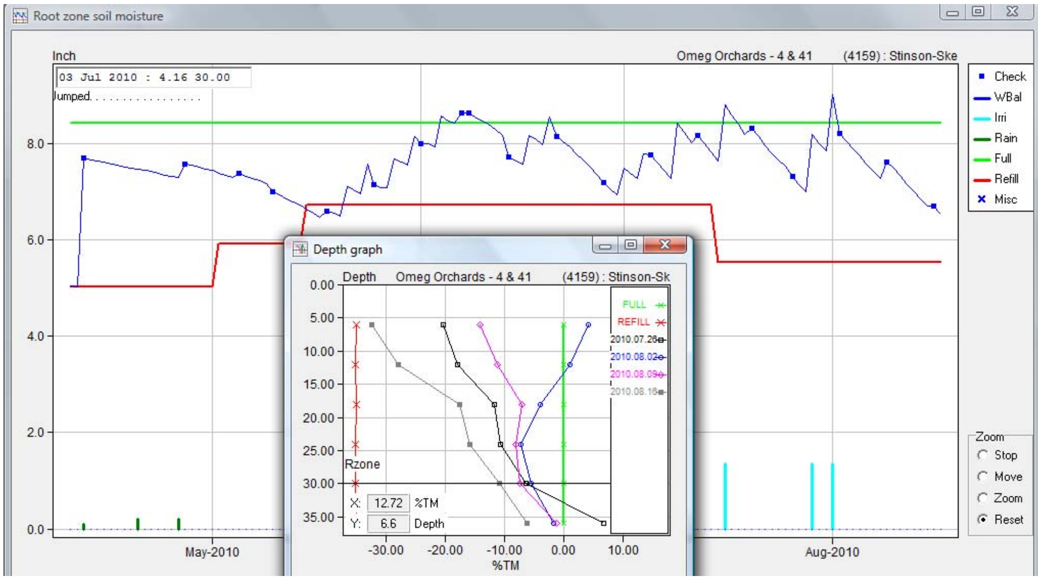


Figure 3 Root zone soil moisture graph and corresponding depth graph

Figure 4. Typical wine grape schedule where soil moisture status is maintained just above the stress level.

The neutron probe access tube and electronic soil moisture sensors are placed in close proximity so as to represent the same wetting and drying in the soil. The electronic sensors are factory calibrated to read 0% in air and 100% in water. These numbers have no direct translation into soil moisture because the calibration curve is not linear and the numbers differ by soil type. Therefore the electronic sensor gives a number that rises and falls with soil moisture content but does not represent actual soil moisture percentage. The neutron probe measurements are used to set the full and refill lines on the graph of the electronic sensor (Figure 5). It was observed that the electronic sensors took several months to reach equilibrium with the surrounding soil however, it remains unclear at this point whether the full and refill lines set in this season will apply in the next season. The electronic soil moisture sensors are discussed in more detail later in this document.

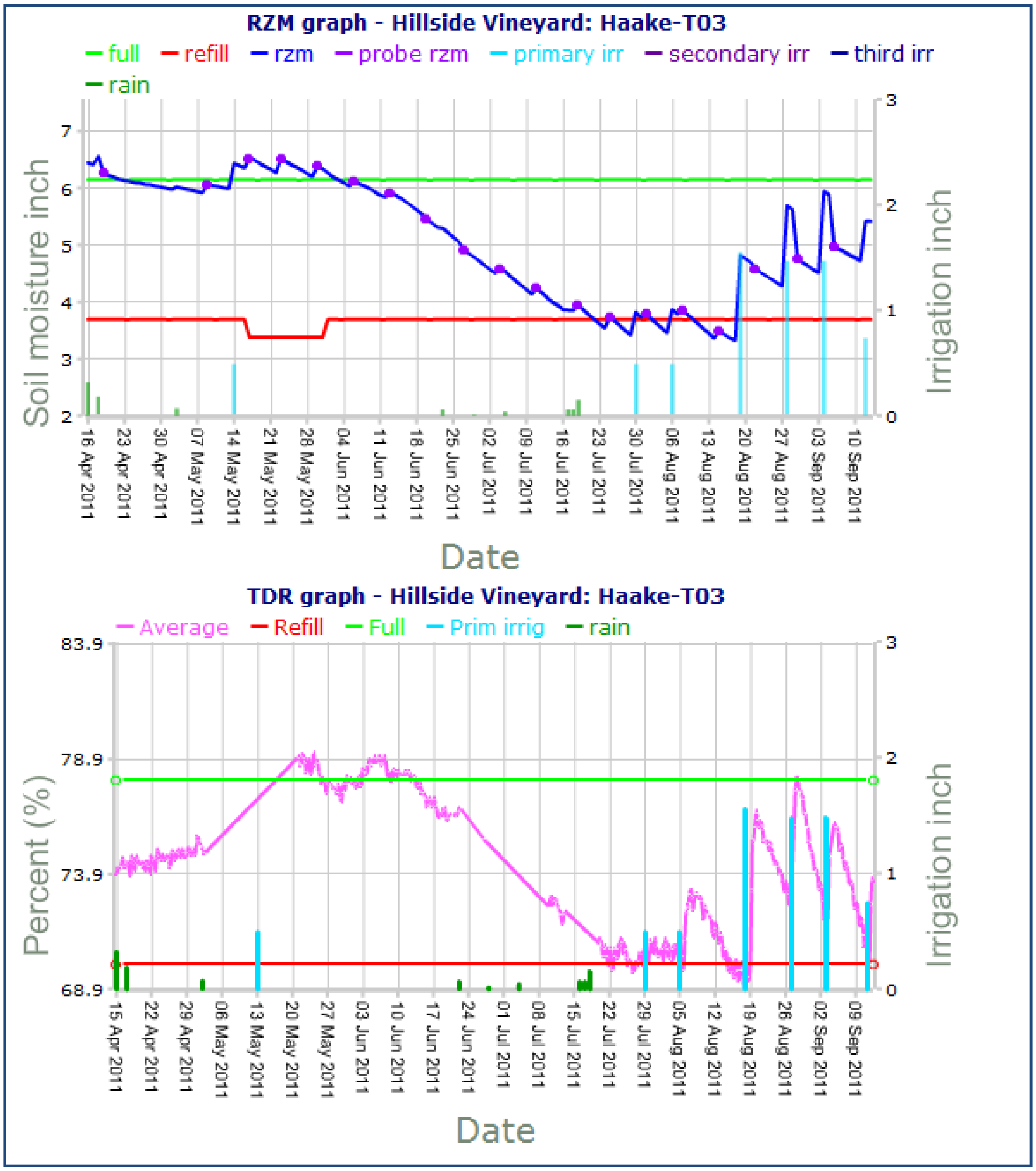


Figure 5. Using neutron probe data to calibrate electronic soil moisture sensor data.

Weather Stations

The model makes use of Eto data obtained from weather stations in the area, usually built and maintained by USDA and universities. In the case of The Dalles, Eto data were obtained from a local IFPnet weather station (supplied by Automata-Inc., CA).

This weather station is telemetry based with data posted on the IFPnet server, where it is then downloaded to the software via RSS feed.

Figure 6. Automata weather station with radio telemetry

Electronic soil moisture sensors

For the Save Water Save Energy project, the choice of soil moisture sensor was the Automata Aquatel-TDR (time domain reflectometry) sensor. Each sensor is 18 inches long and the data it provides is an average over the 18 inches (Figure 7) Two TDR sensors were installed at each monitoring site. The shallow probe was installed at an angle to represent the top 12 inches and the deep probe was installed vertically to represent 18-36 inches. The sensors are connected to a data collector which transmits data via radio signal every 6 hours.

Figure 7. Aquatel-TDR soil moisture sensor

The sensor is factory calibrated to 0% in air and 100% in water. In soil it will give a reading between those numbers that will vary with soil moisture content. The numbers depend on the soil type, with heavier soil giving higher readings and sandier soils giving lower readings. Unfortunately, the relationship between soil type and reading is not exact enough to directly set the full and refill levels based on soil type. Information from the neutron probe is used to set the full and refill levels on the TDR graph. The grower then only has to keep the water level between the full level (green line) and the refill level (red line).

Figure 8. Aquatel-TDR sensors with telemetry station and neutron probe access tube

WEB BASED IRRIGATION SCHEDULING

Growers log into the ProbeSchedule website (www.probeschedule.com) with a unique user name and password to access their data. Each grower can access only his own data; however, consultants can access data for all farms assigned to him.

The user interface of the software is designed to be as simple as possible (Figure 9). The grower simply has to enter his irrigation sets (Figure 10) and then view the latest irrigation schedule report. Eto data are obtained from weather stations in the area or a grower can make use of a number of inexpensive alternatives to generate Eto. In The Dalles, the IFPnet weather station data are rss enables and the Eto and rain data are fed to the software automatically.

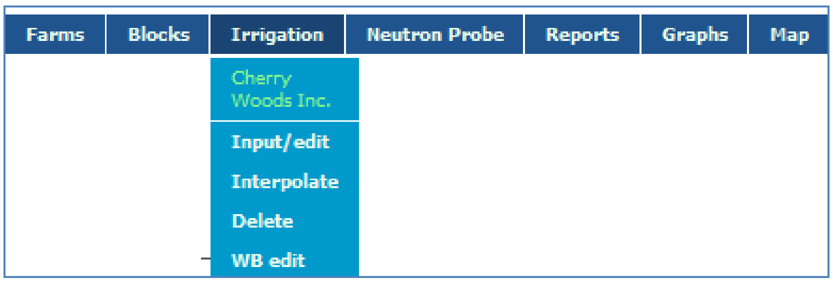
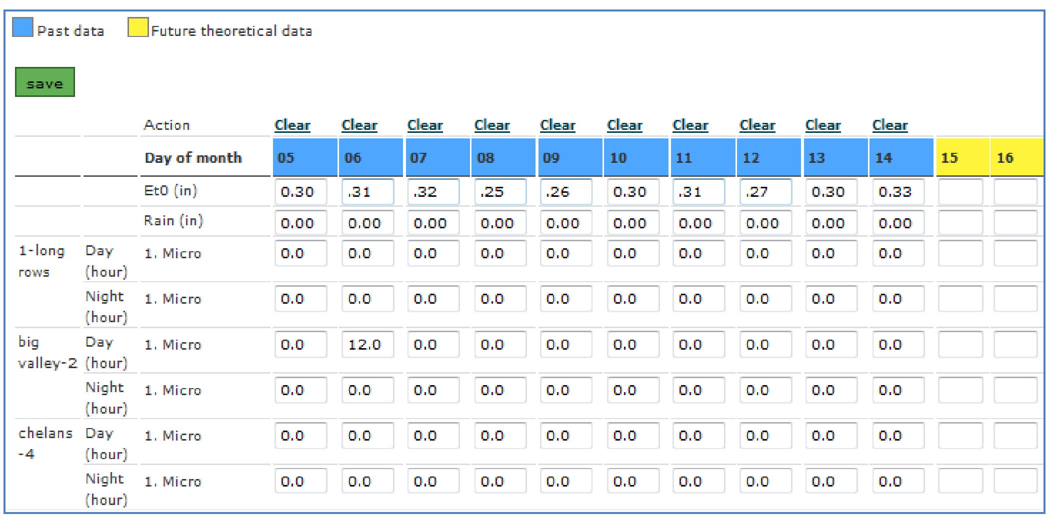


Figure 9. Main menu where Input screen and Reports are selected



Past data Future theoretical data

save

		Action	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear		
		Day of month	05	06	07	08	09	10	11	12	13	14	15	16
		Et0 (in)	0.30	.31	.32	.25	.26	0.30	.31	.27	0.30	0.33		
		Rain (in)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
1-long rows	Day (hour)	1. Micro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
	Night (hour)	1. Micro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
big valley-2	Day (hour)	1. Micro	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
	Night (hour)	1. Micro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
chelans -4	Day (hour)	1. Micro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
	Night (hour)	1. Micro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		

Figure 10. Input screen for irrigation data

The irrigation schedule report can be printed as a priority list so that the grower can water the blocks starting at the top of the list. The report contains detail regarding **when** and **how much** to irrigate and detail of the soil moisture status within the profile, based on the last neutron probe reading. Figure 11 is a sample report, which has been split to preserve legibility. On the report, “Days” refer to the number of days before irrigation is required. A negative number means that the irrigation is overdue. “Hour” is the calculated number of hours, with efficiency factored in, that it would take to refill the profile. For further detail, the grower can view a variety of graphs.

Irrigation Schedule (total moisture)

Recharge: 100% | 2011-08-14

Cherry Woods Inc.

Block	Group	Days	Irri-date	inch	kGal	Hour	Last Probe reading
chelans-4	Dry Hollow	-13	2011-08-01	3.37	92	33.35	2011-08-08
1-long rows	Dry Hollow	3	2011-08-17	2.62	21	29.42	2011-08-08
big valley-2	Dry Hollow	6	2011-08-20	4	27	37.4	2011-08-08
tieton-3	Dry Hollow	6	2011-08-20	1.89	51	18.72	2011-08-08

Last Probe reading	Percentage of Total Moisture remaining at inch depth:						Root zone	Redline	%TM today in Rzone
	6''	12''	18''	24''	30''	36''			
2011-08-08	43	52	58	60	69	75	24.00	-40.0	48.1
2011-08-08	74	81	85	82	92	92	24.00	-40.0	68.1
2011-08-08	93	86	86	78	77	59	30.00	-40.0	73.1
2011-08-08	132	132	107	76			18.00	-30.0	95.1

Figure 11. Irrigation Schedule Report with percentage of total moisture

SAVING WATER AND ENERGY

The purpose of the project was to save energy. Because irrigation water is pumped from the Columbia River to holding ponds on high ground, saving water results in saving energy. Pumping lifts range from 500 feet for the lowest pond to 1,200 feet for the highest.

34 growers were enrolled, covering 3,100 acres of irrigated cherry orchards. The irrigation systems in use are 90% micro sprinkler such as Netafim's Supernet and Nelson rotators with gallons per hour ranging from 15 to 50. The remaining 10% consists of integrated drip line of 0.5 gph every 30 inches and impact sprinklers with discharge in the order of 150 gallons per hour (gph).

Water saving comes from ensuring the irrigation system is working properly and from knowing what the soil moisture status is and irrigating on demand. In general, growers who do not have soil moisture information will start irrigating too soon, resulting in water loss due to deep drainage as shown in Figure 12. At the end of the season, growers often make the profile too wet through unnecessary irrigations as shown in Figure 13. In areas with more than 12 inches of winter precipitation, the profile can be left at 50% capacity, and the winter water will fill it back up. Up to 20% water saving can be achieved by observing the following basic principles:

- Do not start irrigating until moisture level reaches 70% of total soil moisture
- Understand the irrigation system and optimize set size and intervals

- Allow the soil profile to slowly drop to 50% of soil moisture in autumn and do not recharge before winter

Figure 12. Example of a grower who started irrigating too early

Figure 13. Example of filling the profile just before the winter rain starts

In the first year of the project, 3,100 acres were monitored by SIS. The estimated energy saving was 969,215 kWh, or 312 kWh per acre, with a corresponding water saving of 610 acre-feet (198,769,000 gallons). TDID saved $38,768 in pumping cost and the growers combined saved a further $87,840 on their water bills for a total saving of $126,608.

Dollar savings to growers

Saving water and energy translates to the grower saving money on his water bill, even on a small farm. Consider these two examples from TDID, one a 20 acre farm and the other a 100 acre farm.

TDID supplies water to growers at these costs:

$ 80 per acre-ft for first 2 ft
$128 per acre-ft for next 6 inches
$144 per acre-ft for next 6 inches

Cost for a 20 acre farm:

2 acre foot of water @ $80 = $160 x 20 ac = $ 3,200
The next 0.5 ac-ft @ $128 = $ 64 x 20 ac = $ 1,280
The next 0.5 ac-ft @ $144 = $ 72 x 20 ac = $ 1,440

Total cost for 3 acre-foot	**$ 5,920**
Reducing water use by 20% saves	$ 1,653
A commercial SIS service for the year (all inclusive neutron probe service)	$ 1,580
Cost saved by grower	**$ 73**

Cost for 100 acre farm:

2 acre-ft of water @ $80 = $160 x 100 ac = $16,000
The next 0.5 ac-ft @ $128 = $ 64 x 100 ac = $ 6,400
The next 0.5 ac-ft @ $144 = $ 72 x 100 ac = $ 7,200

Total cost for 3 acre-ft	**$29,600**
Reducing water use by 20% saves	$ 8,266
Cost of commercial SIS service for the year (based on neutron probe service, all cost included)	$ 3,700
Cost saved by grower	**$ 4,566**

PROJECT FUNDING

Several funding sources are available for water and energy saving projects. The best way to access these funds (in the USA) is via the local USDA NRCS office which have programs such as EQIP and CCPI. Starting in 2011, energy efficiency is a new focus area that the NRCS is getting involved in and there will be new programs specifically designed for that field. Bonneville Power Administration (BPA) and many other private utility companies now offer an incentive at the rate of between $5.00 and $6.00 per acre for any grower applying SIS.

Funding for the SIS component of the TDID project came from BPA at $6.00 per acre as well as $25.50 per acre from NRCS, which covered the cost of having the SIS done by a consulting company. Funding for the flow meters came from BPA and funding for the electronic soil moisture sensors came from NRCS's national CCPI and AWEP funds.

It is important to stress that an SIS program can be funded by itself, without any additional hardware such as flow meters or electronic sensors.

CONCLUSION

This project has demonstrated very successfully how technology and SIS can be applied to save water and save energy. The take home message can be summarized as follows:

- Saving water saves energy and money
- Funding is available for SIS projects
- Hardware and software is available for SIS
- Help is available to arrange funding and perform SIS

SOUTHERN UTAH WATER SCADA PROJECT AND DISPELLING MYTHS REGARDING 900 MHZ SPREAD SPECTRUM TECHNOLOGY

Dan Steele[1]

ABSTRACT

Each year, the water/wastewater industry deploys an increasing number of spread spectrum communication solutions. Previously, the use of wireless telemetry in water/wastewater SCADA systems was almost exclusively in the licensed radio realm. However, the scarcity of available licensed channels as well as its improved technology has made the spread spectrum radio an increasingly popular choice. With the install base of spread spectrum devices rapidly increasing, there have been a number of urban legends, superstitions and myths that have circulated. With the introduction and advancement of any new technology, misconceptions and misunderstandings will always surface. Spread spectrum, like any technology, can be an extremely valuable tool when used in the correct environment and with correct network deployment.

The objective of this presentation is to explore these “myths” and provide a better understanding of how to use spread spectrum technology in water/wastewater applications and also show where you can expect to succeed with spread spectrum communication solutions. In addition, Steele will provide a real-life, case study example of this technology by exploring the Southern Utah Water SCADA Project.

INTRODUCTION

Problem: How to get reliable and accurate data from hundreds of IO points scattered throughout a very large and diverse topographical area in Southern Utah.

SCADA System understanding and needs:

1) Wider area for source and use of culinary water
2) Network type(s) and architecture to bring the data back
3) Communications – Radio myths, protocols and conversions

THE MYTHS

Many municipal water systems have had to broaden the area from which they gather, use and reclaim water. Most growing areas have had to face the dilemma of higher demands on services while trying to stay within shrinking budgets and manpower cutbacks. While many have seen the need for electronic data gathering, it has been something of a ‘want’ instead of a ‘need’ until now.

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Several years ago, choices were few to address the needs of data gathering and recording. Water utilities had to be able to use a ‘fits all’ unit with set parameters and make their systems adaptable to the technology of the day. Now, a wide variety of equipment is available to render solutions of varying levels which requires an attempt to integrate older systems with newer technology where possible. We’ll discuss issues faced while trying to minimize expense and methods to gather data from a wide geographical area with diverse topography.

As the installed base of spread spectrum devices has increased, a number of myths, misconceptions or “urban legends” have begun to circulate. You may have heard of some of these myths:

- **Security**: Spread spectrum is not secure; your data can be stolen or tampered.
- **Saturation**: Spread spectrum radios will shut down when there are too many radios on the same frequency or in the same area.
- **Range**: Spread spectrum devices output only 1 Watt, so can’t perform as well as licensed radios that have 2 or 5 watts of power.
- **Compatibility**: If you are using licensed radios, you can use only licensed radios and/or repeaters to expand your network.
- **Interference**: If you mix licensed radios with spread spectrum units or different brands of spread spectrum radios in the same system, interference and lost data will result.
- **Obstruction**: You must have a clear line of sight, or spread spectrum will not communicate.

But none of these statements are accurate.

Misconceptions always will accompany the advancement of a new technology. Spread spectrum is an extremely valuable tool when used in the correct environment. Exploring each of these “myths” will provide a better understanding of how to apply the technology and where you can expect to succeed with spread spectrum communication solutions.

DISPELLING THE MYTHS

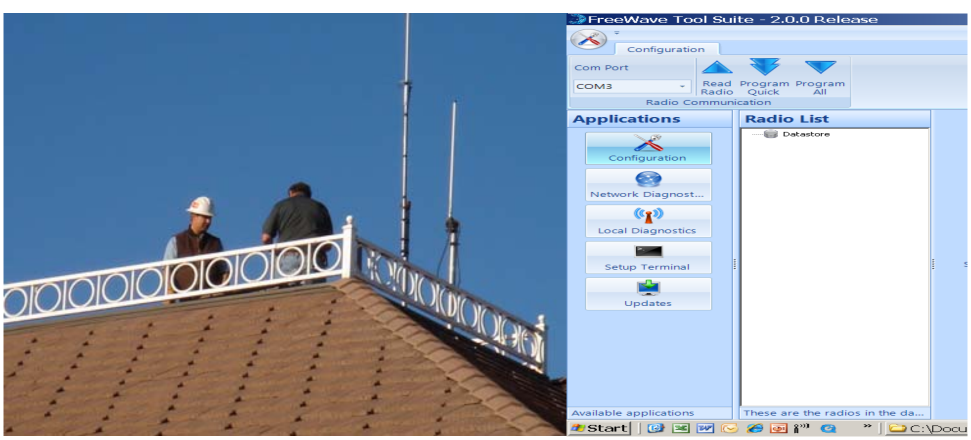

Figure 1. Installing spread spectrum wireless data radios

Wireless data radios are very secure and have several parameters that protect the system from security attacks and allow several thousand radios to be collocated in the same area. Today, you can have a mix of Ethernet, Serial, IO and Cathodic Protection radios all on the same network that are able to receive data in several ways and protocols. The most common use of a protocol will be explained below, but the ability to send water tank levels, pressure readings, water flow measurement, security alarms and even video images back to the Water utility operators' office is not just convenient. . . it is critical. With Ethernet Radios you have the ability to look at the SCADA system anywhere in the world with an IP connection. This is incredibly valuable to Water system operators, Water districts and utilities.

The first issue to resolve when transmitting data from one point to another is protocol. In the context of data communication, a network protocol is a formal set of rules, conventions and data structure that governs how computers and other network devices exchange information over a network. In other words, protocol is a standard procedure and format that two data communication devices must understand, accept and use to be able to talk to each other. Odd as it may seem, there are many choices to pick from in this area -- whether you are transmitting via hardwire, telephone line, cellular, satellite, microwave, fiber optic or ISM band wireless radios. Many of these options are carryovers from a time when data transmission was first attempted and there were as many types of protocols as there were personalities trying to solve this issue. Each thought theirs was the best method and each different protocol addressed a pet issue with the developer, but did not address all issues facing the end user.

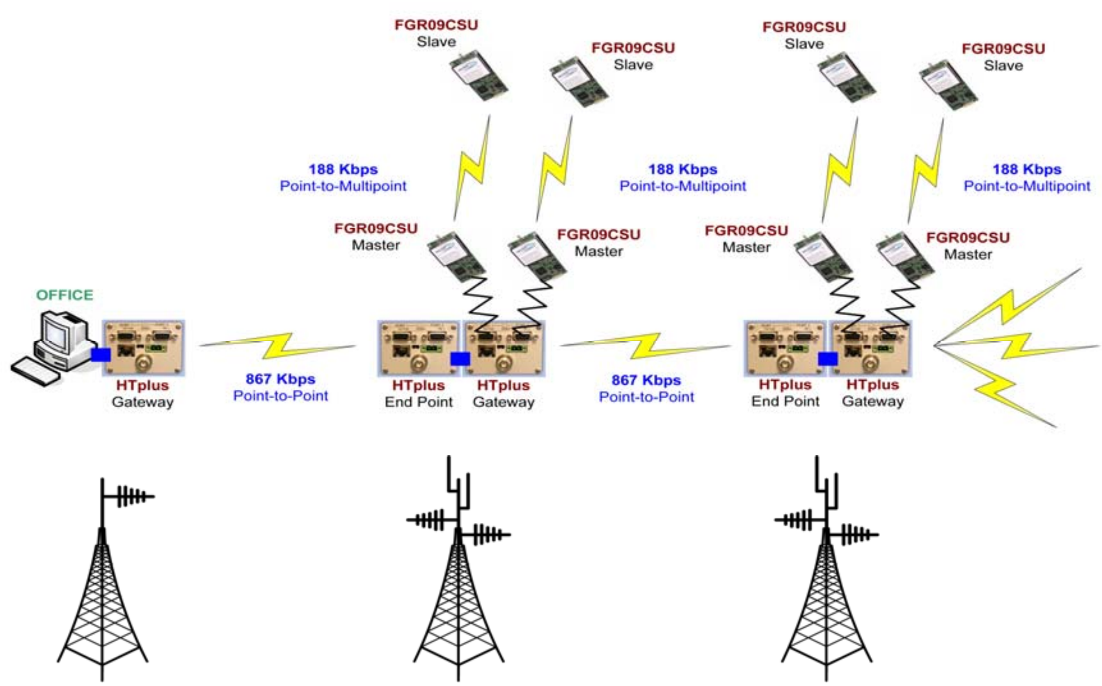

Figure 2. Polling multiple networks at the same time

One protocol that has, for the most part, become a standard for a majority of devices is ModBus. Today, the ModBus protocol is the single, most supported protocol among automation devices. Most devices, being able to communicate serial, talk ModBus or can be configured to do so.

One ray of hope when integrating older technology with new technology is being able to pass data using the ModBus protocol. Integration of data systems often will utilize this protocol for many areas where small pockets of data are to be gathered and transferred to the systems 'backbone' where the data is sent to the main control and gathering area. This is where the term "SCADA" (System Control And Data Acquisition) was implemented.

Using these methods of coverage, the network has a backbone system that is more than 100 linear miles in length and branches out -- covering many more miles. The IO count is in the thousands, with more than 200 data sites. The sites are a mix of utility-powered and solar-powered devices, with the solar sites designed to perform for several cloudy days without interruption of service. The combination of hardware with the ModBus protocol has also minimized the need to replace or upgrade field hardware.

We also have found that, more often than not, there is more than one water district in areas of coverage in the larger metropolitan areas. This may be county and city entities or several cities in close proximity. To further minimize costs, we've assisted these agencies with formation of MOU's (Memorandums of Understanding) to allow them to utilize the same backbone and/or data points, reducing duplication of effort. This has worked well with the ability to secure separate systems, passing only data contained in their MOU's from one to another. Most large districts have their own IT departments, and once they are assured everything in their world is secure, they are very helpful in setting up security and routing data to the correct system points.

CONCLUSION

900MHz Spread Spectrum Radios are secure, robust, have several different communication interfaces for serial, Ethernet and IO. The radios transmit the data fast, are easy to deploy and can expand the network easily as the system grows. They can be used for several different applications at the same time on the same network. The user can use the radios with other types of communication equipment to utilize the infrastructure that may be in place. Each radio can be a repeater if necessary for greater coverage. The new IO radios offer very high IO counts and with Modbus the capability to have more than 65,500 devices on the same network. Ethernet radios have faster speeds, reduce the polling time and can connect any type of IP device to the network, and security cameras can be deployed to monitor the network. The Water utilities have more time to maintain the water system and be able to do preventative work on pipelines, valve installations and meter connections. Municipalities or Water utilities in the same area may be able to combine or share some of the infrastructure costs and engineering.

ACKNOWLEDGEMENTS

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PIPELINE AND CANAL DOWNSTREAM CONTROL SYSTEM FOR RECIRCULATION — PATTERSON ID CASE STUDY

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ABSTRACT

Patterson ID in Central California has five long, along-the-contour lateral canals that flow northward from a main canal. The main canal operates on downstream control, providing excellent flexibility to heads of the laterals. The lateral canals operate with manual upstream control and have little storage. The classic tail-ender problem existed; spill from the tail end was necessary to avoid under-supplying tail-end customers.

To eliminate the spill and to provide better flexibility, a system was designed and constructed to tie the ends of the five laterals together with pipes and pumps, with one central regulating reservoir. The automatic control system allows water to exit a lateral pool by gravity if that particular lateral end has too high a water level. Conversely, if the most downstream pool on a lateral canal drops, a VFD-equipped pump from a downhill lateral automatically supplies the correct flow rate to re-establish a constant water level. The same pipe is used for flow in both directions.

Any excess flow from the system as a whole is automatically routed to the reservoir. Any deficit from the system as a whole is removed from the reservoir. The complete system is monitored by SCADA, so operators know where excesses or deficits occur, and can adjust flows at the heads of the laterals to compensate for mismatches at the ends of the laterals.

The system has worked successfully for three irrigation seasons. The paper describes the control philosophy, design, costs, challenges, and benefits.

INTRODUCTION

Patterson ID — Background

Patterson Irrigation District (District) is located in Stanislaus County on the west side of California's San Joaquin Valley. The District provides irrigation water service to nearly 13,500 acres of farmland situated between the City of Patterson, CA and the San Joaquin River. The region produces a variety of crops including hay and forage crops, tomatoes,

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beans, vegetables, almonds, walnuts, and stone fruits. The District's customer base is predominately small family farms and ranchettes, with most parcels ranging between 10-40 acres in size. Because forage crops account for approximately 55 percent of the acreage within the District, furrow and border strip irrigation is the primary method of irrigation. Over the past six years, however, the District has seen a 40 percent increase in acreage utilizing drip/microsprayer and sprinkler irrigation systems, corresponding with a similar increase in almond and walnut orchard establishment.

The District supplies water through the operation of four miles of main canal lift system and over 50 miles of along-the-contour lateral canals which convey water to lands north and south of the main canal. The main canal includes six pump stations with 33 pumps to deliver water to thirteen laterals. Each pump station utilizes downstream control with a Proportional Integral Derivative with Filter (PID-F) algorithm to maintain the water level in the canal pool within $\pm$ 0.10 feet. At least one variable frequency drive is used at each station to provide infinite flow rate possibilities for more precise canal control. A map of the District is provided as Figure 1.

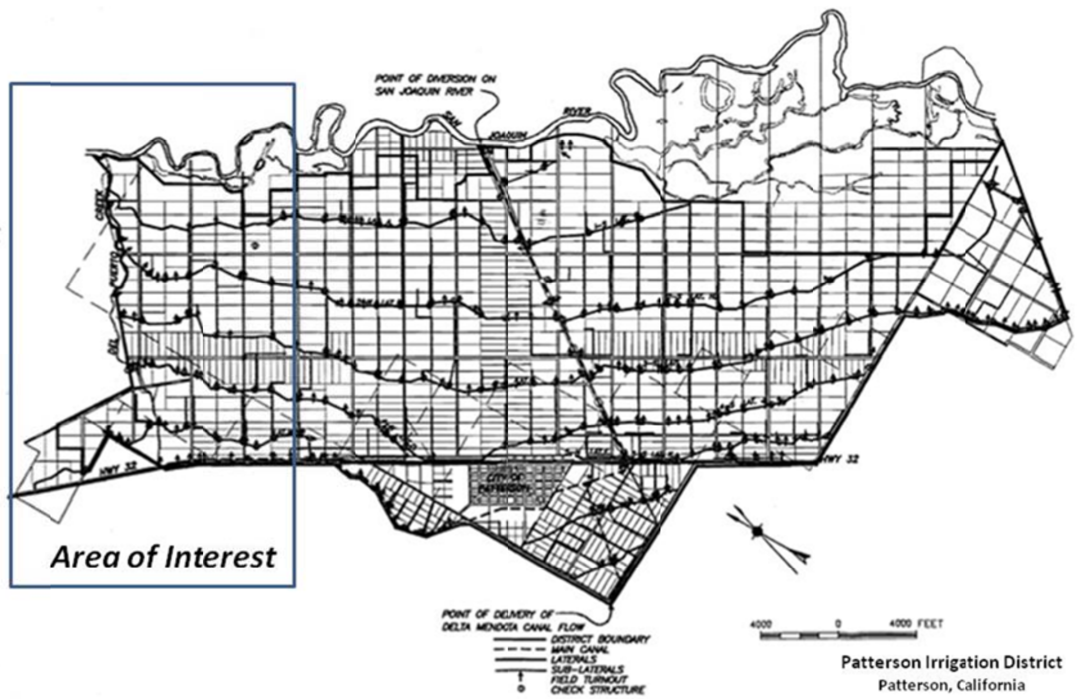

Figure 1. Patterson Irrigation District delivery system.

The majority of the laterals off of the main canal are operated with manual upstream control, although the District recently installed two automated flow control structures at the heads of two laterals on the main canal. Operators typically use a flume at the head of each lateral to set the desired flow rate, based on the orders for the day on each lateral. A typical flow structure is shown in Figure 2. The automated flow structures utilize level transducers, a gate actuator, and orifice flow equations to set and maintain flow rates into two laterals off of the main canal. For both manual and automated control structures, the main canal responds to level changes on the system and automatically determines pump flow changes to maintain the desired levels in each pool.

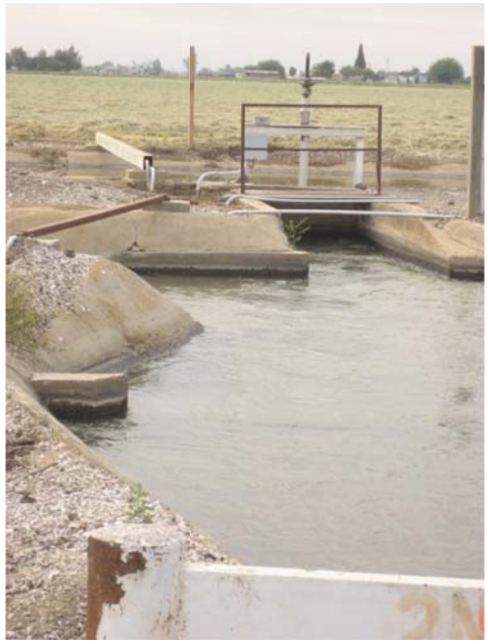

Figure 2. Head of Lateral 2N.

Over the past 14 years, the District has implemented an aggressive modernization program which has included the following: main canal automation; Supervisory Control and Data Acquisition (SCADA) and radio communications for remote monitoring and operation of District facilities; standardization of all pump motor control center installations; construction of regulatory reservoirs to capture and recirculate operational spill and agricultural drain water; and most recently, completion of a California Department of Fish and Game/National Marine Fisheries Service-approved fish screen on the district's San Joaquin River diversion. These improvements have increased conservation and efficient use of water supplies, which include the San Joaquin River, groundwater, and gravity-fed Central Valley Project water from the Delta-Mendota Canal. They have also added flexibility to the operation and ordering within the District. The District generally requires 24-hour advanced notice for water deliveries and two to three hours for water shut-offs. If capacity is available, however, water orders can be accommodated immediately and shut-offs can be accommodated within 1-2 hours of advanced notice.

Lands within the District are generally irrigated from west to east, following the natural contour of the area. Water is delivered to a field from the westernmost lateral, and drains into the next easterly lateral. As a result, operators typically estimate an amount of anticipated drainage to expect when setting flow into each lateral. Additionally, the laterals were designed with little additional capacity to meet peak season demand, and no storage. These factors made it difficult to set the correct flow to minimize operational spill and meet grower demands at the end of each lateral for years. Any agricultural drainage and operational spill would historically outfall into the Marshall Road Drain to the south or the Del Puerto Creek to the north, both tributaries to the San Joaquin River.

PROJECT CONCEPT

The District, in trying to address CALFED's targeted benefits on the San Joaquin River, completed the first phase of a master plan to reduce contaminant loading to the San Joaquin River by improving the operation of the Marshall Road Drain, situated in the southwest corner of the Patterson Irrigation District in 2002. The objectives of this modification were to: reduce the silt loading to the San Joaquin River; reduce Organophosphorus (OP) pesticide levels in the drainage water discharged to the San Joaquin River; reduce constituents adversely affecting the dissolved oxygen level within the San Joaquin River; and develop new water supplies through construction of operational spill and tailwater recovery systems to further improve the local efficiency of water management.

This effort necessitated the cooperation of various local agencies since the watershed tributary to Marshall Drain consists of approximately 6,800 irrigated acres located within Central California Irrigation District, Del Puerto Water District and Patterson Irrigation District, with a smaller area independent of local agencies. Silt-laden upslope surface drainage and operational spill water historically discharges from these areas into the Marshall Road drain and then into the San Joaquin River.

A surface tailwater collection reservoir was constructed with a surface area of 14 acres and usable storage capacity of 42 acre-feet. The operation plan for the reservoir was to divert as much of the watershed surface tailwater drainage as possible and use it as an irrigation supply for approximately 850 acres downstream of the reservoir on Lateral 3-South. The implementation of the project reduced direct discharges of constituents to the San Joaquin River and allowed opportunities for improved water management by recycling this drain water back into the local irrigation supply.

Building upon the success of the south reservoir program, the District proposed construction of another reservoir/impoundment on the northern end of the District to prevent/reduce operational spill, improve service to landowners on the tail-end of the system, and to also meet the following objectives:

1. Develop cooperative and coordinated real-time salt and nutrient drainage load reduction strategies through enhancements to existing flow and water quality monitoring networks.
2. Plan, design, construct and operate a drainage detention pond within the District to meet CRWQCB objectives of salt and nutrient load reduction to the San Joaquin River while enhancing water supply reliability in the District.
3. Enhance effectiveness and efficiency of operation of on-farm irrigation and drainage facilities and practices in neighboring West Stanislaus Irrigation District through design and application of a real-time monitoring and diversion control system and associated irrigation and drainage best management practices (BMP's).

4. Monitor, evaluate and contrast the performance of irrigation district-owned and privately-owned drainage detention facilities and operational strategies. Develop BMP's for real-time operation of similar projects and on the west side of the San Joaquin Basin.

The initial project concept included a series of pump stations and interconnecting pipelines that would convey excess agricultural drainage and operational spill between laterals and into a reservoir on the northern end of the District. The reservoir would store water that was historically spilled to Del Puerto Creek and the conveyance system would recycle this water to the laterals to meet crop demands at the tail end of the system. This concept is illustrated in Figure 3.

PID was awarded two grants for development and construction of this project: a Proposition 50 Agricultural Water Quality Grant through the California State Water Resources Control Board in 2004, and a CALFED Water Use Efficiency Grant in 2005. Both grants totaled approximately $1.7M toward design and construction of this project, with the District originally pledging approximately $1.3M in funds toward the project.

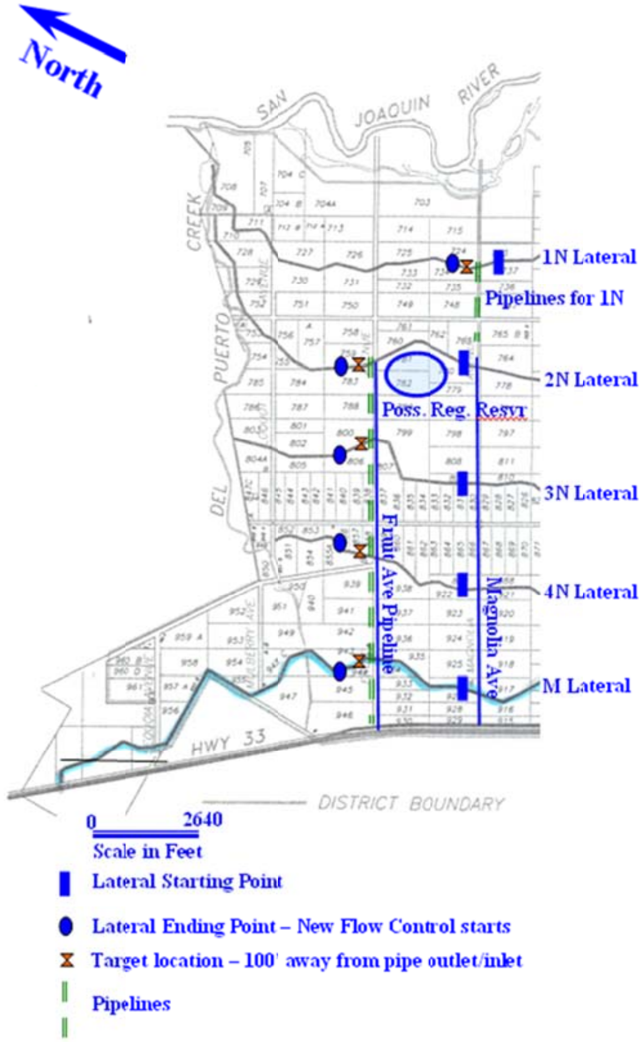

Figure 3. Early conceptual sketch for the project.

PROJECT DESIGN

The District worked with staff from Summers Engineering out of Hanford, CA, Berkeley National Laboratories, the Irrigation Training and Research Center at Cal Poly, San Luis Obispo, and neighboring West Stanislaus Irrigation District to develop a regional, multi-benefit project to meet the project objectives. This project included the design, installation, and operation of a regional reservoir within PID to store and divert excess drainage water and operational spill flows for reuse within the PID system. As part of the SWRCB grant agreement, a local field-level drainage recirculation system was also constructed and installed so that the costs/benefits of the various drainage-storage and reuse strategies within the local region could be computed. The project was broken into two separate project components: (1) a Northside Recovery System (Northside Reservoir), which includes a regional reservoir within PID and interconnecting pipeline and pump facilities between laterals; and (2) the Westley Tailwater Return System.

The Northside Reservoir project design was unique and challenging. Design objectives included:

1. No spill from the ends of any of the five laterals during normal operation.
2. Provision for emergency spill from the lateral ends in case of power failure or errors in control.
3. Only one reservoir, due to the costs of reservoir construction and land purchase.
4. No flow rate shortage at the ends of any of the five laterals during normal operation.
5. Completely automatic operation.
6. Remote monitoring of the status of the pumps, valves, and lateral reservoir water levels.
7. Ability to remotely change target depths of water in the laterals, or to over-ride automation and be able to remotely manually control the operation.
8. Stable and rapid control.
9. Fairly constant water levels at the ends of the laterals, regardless of the flow.
10. Operation without knowing any of the turnout flow rates.
11. Distributed control.

Figure 4 shows the general control concept. Lateral 4N will be used as an example for discussion. The logic was the same or very similar for all other laterals.

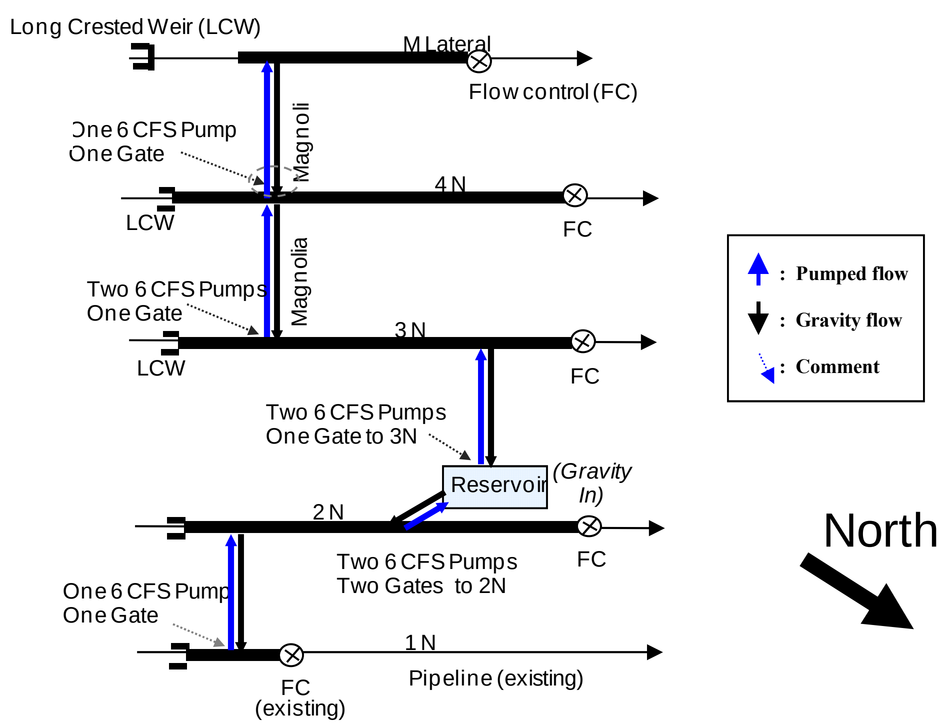

Figure 4. Final configuration. Note that "North" is oriented differently than in the previous figures.

For lateral 4N, the only Programmable Logic Controller (PLC) that examines the water levels in 4N is located between it and the reservoir – at the pump station located on lateral 4N. If the water level in lateral 4N drops below the target, there are two types of action possible:

1. Reduce the flow out of 4N. Control-wise for "demand" operation, this can only be accomplished if water is flowing from 4N to 3N. In this case, water would be flowing downhill from 4N through the single pipeline. A modulated valve adjacent to the pumps on 3N would be closed the appropriate amount, reducing the flow from 4N.
2. Increase the flow into 4N. If the modulated valve on the pipeline between 4N and 3N is completely closed, the pumps would be turned on. Water would flow through the same single pipeline as in (1) above, but this time it would be pumped uphill from 3N to 4N. The pumps are equipped with variable frequency drive controllers, so the speed is carefully adjusted by the PLC to provide exactly the change in flow rate needed to stabilize the water level in pool 4N.

The cause of water level fluctuations in 4N could be an increase or decrease in turnout flows directly from the 4N lateral, or from flow rate changes to/from lateral 5N.

Prior to the construction, the laterals and pipelines were simulated for unsteady control conditions associated with downstream control. It was found that some of the canal pool banks needed to be slightly raised to achieve the required control stability. The pools were physically modified as part of the modernization process.

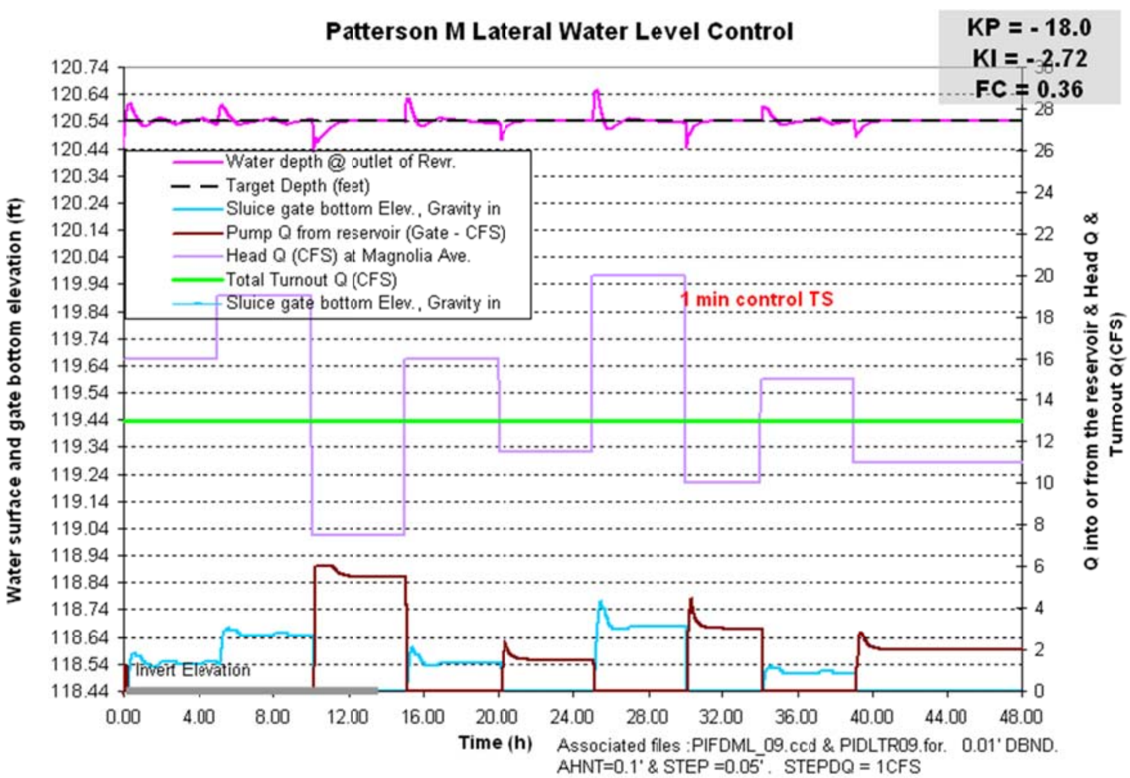

Figure 5. Example simulation results prior to final implementation.

Simulation procedures such those illustrated in Figure 5 assume that when the control requires an increased flow of 0.23 CFS, for example, that precise flow rate is available. Actually achieving that desired change in flow rate in the field control requires excellent knowledge of the characteristics of the valves and pumps. Figure 6 shows how one pump curve at multiple speeds reacts with the system curve. The problem becomes somewhat more complex in some of the pipelines because two pumps are used on the same pipeline, rather than just a single pump.

After the construction, Patterson ID personnel performed trial pump tests to determine the actual pump discharges at various speeds. That refined information was incorporated into the control logic to improve performance, although the initial performance was already very good.

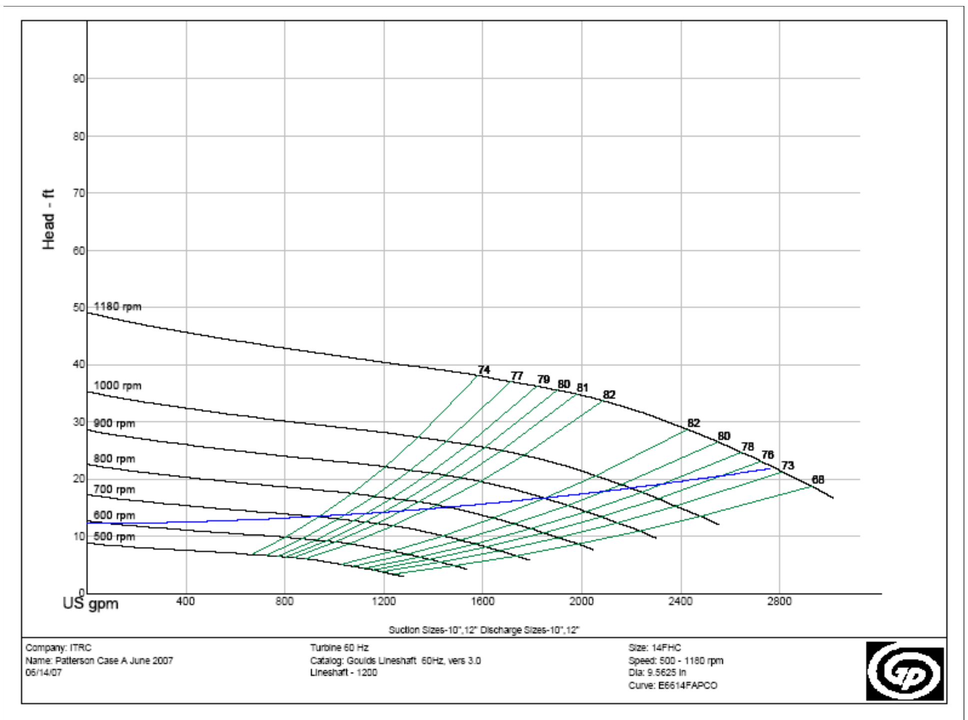

Figure 6. Example pump curves and system curve.

CONSTRUCTION MANAGEMENT

The District took a very hands-on approach to overall construction management for the project. A number of contractors were hired under separate contracts for various aspects of the project including pre-cast concrete products, earthwork, pumps, flow control structures, electrical, and SCADA integration. Throughout the project, District staff, along with engineers from Summers Engineering, managed and coordinated construction schedules between contractors to ensure that the project was completed on time. District staff also coordinated with engineers for regular construction inspection and progress reporting.

Figure 7. Earthwork to establish reservoir levees and rip rap for levee protection.

Figure 8. One flow control structure to the north of Fruit Avenue with weir length designed to pass high flows under system failure conditions.

Figure 9. Pump station and valves to divert water from the reservoir into 3N or vice versa

Upon completion of the construction, the District installed heavy security measures for the overall project in an effort to prevent the vandalism and copper-wire theft that had occurred to local landowner pumps and wells in the region. These measures included concrete vaults to house motor-control centers, burglar alarm panel/PLC’s, anti-climb fencing with vibration detection, magnetic locks, sirens, and strobe lights. These improvements were financed directly by the District.

The Westley Project included the construction of a two-stage tailwater collection reservoir and a return pump station and pipeline. The reservoir collected tailwater from a 550-acre field into an initial settling cell. The purpose of the settling cell was to settle out the suspended silt in a relatively small pond that could be cleaned easily. As the initial cell filled, tailwater was decanted into the primary cell through a flashboard riser, where it was stored until it was needed for irrigation. A pump station was constructed on the down-slope end of the primary cell which would pump the stored tailwater through a ½-mile long pipeline, where it was blended with surface water and used for irrigation. This project is shown in Figure 10.

Figure 10. Westley Project tailwater collection and return system.

<u>Control Implementation</u>

The implementation of the automation required careful specifications in advance, as well as close cooperation between the integrator company (Sierra Controls of Carson City, Nevada), the civil engineering firm in charge of the construction drawings (Summers Engineering of Hanford, California), the irrigation district, and ITRC. ITRC was responsible for the control concept, specifying the equipment and logic development, simulation, and programming. The automation was accompanied by a new Supervisory Control and Data and Acquisition (SCADA) system. The integrator was provided, in advance, with all of the tag and register locations for the control logic. The control logic was written in the ISaGRAF language, which is standard for ITRC.

The integrator first established the new, expanded SCADA system by upgrading an older system using Lookout® with newer ClearSCADA® software and associated hardware. All communications use spread-spectrum radios, although the office server can be accessed via the web to perform any functions possible at the office itself.

After the integrator had installed the field sensors, radios, antennas, RTUs, and other equipment, the control software was downloaded. The logic communications with the office were verified, site by site. ITRC and the integrator worked side by side to verify instrument calibration, correct implementation of register assignments, and the other multiple details that must be checked before commissioning a site. The automated logic was then implemented. Due to the simulation testing and control constant tuning that was done in advance of the implementation, only very minor adjustments were needed.

As is standard with VFD installation (pump curves and required pressures do not always match design assumptions), the actual pump flow rates needed to be verified by the district at various RPMs. The appropriate adjustments were made to the pump flow constants within the PLC.

The system uses redundant water level sensors, and also features emergency weir overflows at the downstream end of each controlled pool. The SCADA system provides alarms in the event of discrepancies between sensors, failures of pumps and valves, high or low water levels, and other critical items.

Magnetic flow meters were installed on the flow control structures, and on each interconnecting pipeline. One of the benefits of utilizing magnetic flow meters in this application is that since the pipelines were designed to convey water in two directions either by pumping or gravity, a single magnetic flow meter can read flows in both directions. A typical flow meter installation is shown in Figure 11. All of the flow meters communicate with the District's SCADA system, allowing staff to monitor and record all flows for the project, trend current and historical data, and troubleshoot operational issues.

Figure 11. 1N pump station magnetic flow meter

OPERATION

The Northside Reservoir has been in operation now for nearly three full irrigation seasons, and functions as intended, achieving level control in each lateral pool, and flow control downstream of this project. District distribution system operators can set flows for tail-end landowners and water users from the office and in the field, delivering precisely the flow ordered. All conveyance to and from the reservoir and in between the laterals is automated, based strictly on level-control in each lateral pool. The project has met all of the objectives it was designed for, including water conservation, storage and recycling, as well as improved operational flexibility to meet tail-end water demands. Furthermore, various HMI screens created for the reservoir project allow staff to operate, monitor, and troubleshoot nearly all components installed for the project.

Maintenance of the project has primarily involved weed control, rip-rap erosion protection installation, and regular pump and valve maintenance. After two years of operation, the reservoir has not required cleaning and removal of sediment deposits, which can accumulate as sediment-laden drainage water is stored. It is anticipated that this type of activity will be required every three to five years. Minor control calibrations have been performed over the year, although these activities are relatively seamless as SCADA integrators and consultants have the ability to remotely log-in to troubleshoot and modify control parameters.

In order to estimate overall Northside Reservoir conservation and performance over an irrigation season, and to compare the larger regional reservoir project to the landowner-based Westley Project, data from 2010 was reviewed and used to compute conserved water volumes. Flow data for the Northside Reservoir project was downloaded from the District's SCADA system for the months of March through October of 2010. This flow data included flows into and out of the reservoir, as well as flows between laterals. During this time period, approximately 2,300 acre-feet of water were conserved through the operation of this project. This includes approximately 1,500 acre-feet of water that was stored and used directly from the reservoir, and another 800 acre-feet of excess water that was diverted to meet adjacent lateral demands or deficits.

Electrical usage data for the project were also analyzed to determine project use energy, which was then compared with overall District energy consumption. For the same 2010 period, the project utilized approximately 82,400 kW-hrs of power, primarily for the operation of pumps and gate actuators for the project. After applying the District's average monthly power rates, project energy consumption costs are approximately $2.14 per acre-foot of water conserved. For comparison, the District's average electricity cost to divert water from its various supplies during the 2010 irrigation season was $7.72 per acre-foot. These conserved supplies allowed the District to augment diversions and pumping by a similar volume, which equated to approximately $5.58 per acre-foot, a 72 percent cost savings in electricity per acre-foot of conserved water. Given annual maintenance costs of $13,000, the total cost for reservoir operations, based on conserved quantities, is approximately $7.80 per acre-foot.

The landowner operating the Westley Tailwater Return Project was interviewed to determine the Westley Project's costs and quantities conserved. According to the landowner, the tailwater return system costs approximately $6,000 to operate annually, which includes maintenance costs for weed control, electricity, and annual sediment removal and maintenance. During an irrigation season, the grower noted that approximately 400 acre-feet are captured and reused as a result of this project. This equates to approximately $15/acre-foot, and approximately $45 dollars in savings when comparing the grower's direct per acre-foot costs from the local irrigation district, or a 75 percent cost reduction for conserved water made available through the tailwater return system. In regards to electrical costs alone, the project costs the landowner approximately $5 per acre-foot to operate.

CONCLUSION

When comparing the intended results of the district regional drainage recirculation project and the landowner farm drainage recirculation projects to the actual results from operations there are several positive observations as follows:

1. Both projects were able to successfully impound and recirculate surface drainage water for application as consumptive-use irrigation water on crops.
2. Both projects were able to reduce the amount of silt and constituent-laden surface drainage water which otherwise would have ended up in creeks, streams and rivers, thereby meeting the CVRWQCB objectives of salt and nutrient load reduction to the San Joaquin River while enhancing water supply reliability in the District.
3. Both projects resulted in increases in operational efficiency when considering initial diversions in-district or applied water on farm through applying recirculated surface drainage water as opposed to applying water from primary initial sources such as water rights, contract and groundwater diversions.

There appear to be some straight economic advantages when comparing the cost per acre-foot of recirculated water on the landowner project vs. the district project. Including capital amortization and O&M costs, the landowner project's recirculated water comes at an annual present cost of approximately $26.50 per acre-foot when compared to a cost for the district project's recirculated water of $63.50 per acre-foot. These are the non-grant capital subsidized costs per acre-foot. If the grant funding is excluded from the true capital cost of the project's the annual cost per acre-foot of recirculated surface drain water is approximately $16.45 for the landowner project and $37.40 for the district project. As mentioned previously this is a cost savings per acre-foot for the landowner so the landowner is actually avoiding a higher cost and realizing a savings. In the district case the average true cost of delivering its melded primary water supply sources (water rights, contract water and groundwater) is approximately $55 per acre-foot. The grant subsidized capital cost yields a cost savings per acre-foot for the district when compared to its alternate water supplies but only when grant funds offset the overall capital cost. Additionally, the district has the option to consider alternate beneficial uses for the water rights and contractual water supplies which otherwise would have been diverted to the project benefit area absent the project, such as water transfers. In general, water transfers have generated revenue for the district to complete these types of multi-benefit projects which generally require significant capital outlays.

There are several non-monetary advantages the District realized by completion of this project:

- An avoided incalculable cost of further regulatory compliance regarding concerns with silt and constituent-laden tailwater reaching natural water bodies
- A drastic improvement in customer service through the implementation of a sophisticated, automated project that has created a new water source at the tail-end of one-half of its distribution system. This new water source allows the system to meet growers' demands for instant turn-ons and shut-offs, eliminating

the need for tail-end water customers in this area to divert groundwater to make up for the District's inability to meet their full water needs.
- The ability to continue to provide surface drainage capabilities to farms in the affected area, as the project can now easily handle the irregular drainage flows.

Additionally, data continues to be gathered on the amount of silt outflow reduction from both projects. Constant annual estimates from the District's prior recirculation project experiences indicate a fairly consistent annual relationship of one cubic yard of sediment outflow reduction per acre-foot of recirculated water. The landowner project has needed to perform sediment basin removal a minimum of once per year and the district project appears to likely only have to complete sediment removal approximately once every five years.

For both projects the best management practice ultimately implemented was the capture, recirculation and crop-irrigation application of nearly 100% of the surface drainage water in the project areas. The District will continue to gather data on water quality, as well as examine operational costs to further refine cost and water quality benefits of both projects.

MAIN CANAL DECISION SUPPORT SYSTEM FOR SCHEDULING FLOW CHANGES ON MAIN CANALS IMPERIAL IRRIGATION DISTRICT EFFICIENCY CONSERVATION PROGRAM

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ABSTRACT

In 2003 the Imperial Irrigation District (IID, or District), a 450,000-acre water district in Southern California, was one party to a package of decisions and agreements known collectively as the Quantification Settlement Agreement and Related Agreements (QSA). Under one aspect of the QSA, IID agreed to a long-term transfer of water conserved within the IID to the San Diego County Water Authority (SDCWA) and the Coachella Valley Water District (CVWD). IID must conserve and transfer 303,000 acre-feet of water each year, nearly 10% of the District's total annual water use, by 2026. In 2007, IID completed the Efficiency Conservation Definite Plan (ECDP) outlining strategies for delivery system and on-farm water savings. Although court review of some aspects of the QSA continues, the parties have agreed to continue to abide by the agreement. This paper describes the Main Canal Decision Support System (MCDSS) developed by IID to support main canal flow change scheduling decisions. The IID distribution system consists of three main canals, 11 regulating and interceptor reservoirs, more than 200 laterals, and over 5,500 deliveries to users. The MCDSS was developed within IID's Water Information System (WIS) to assist IID Water Control in operating this large, multifaceted water distribution system with maximum efficiency while providing delivery flexibility, responsiveness, and reliability to IID water users. The MCDSS supports IID's main canal water delivery scheduling and daily water accounting processes; and automates IID's long standing paper processes in a manner that eases the transition for main canal operators. The MCDSS is an integrated collection of decision support tools designed to provide support to Water Control Center (WCC) main canal operations. Meeting these objectives required developing a system of complex computer applications integrated within the MCDSS framework. The MCDSS development process and modules will be described in this paper.

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BACKGROUND

The Imperial Irrigation District (IID) was established 100 years ago and delivers Colorado River water for irrigation to approximately 450,000 acres in Southern California (Figure 1). The IID distribution system consists of three main canals, 11 regulating and interceptor reservoirs, more than 200 laterals, and over 5,500 deliveries to users. The water delivered to growers supports the production of a significant portion of the winter vegetables consumed in the United States. Other significant crops include alfalfa and other hay crops supporting dairy and livestock industries. Imperial County in California ranks as one of the top counties in the United States in terms of gross agricultural production and sales primarily due to the Colorado River water supplied to growers by the IID.

Figure 1. Imperial Irrigation District Location.

In October 2003, the IID entered into the Quantification Settlement Agreement (QSA) and Related Agreements. As part of these agreements, the IID agreed to a long-term transfer of water to the San Diego County Water Authority and the Coachella Valley Water District. To enable IID to meet its water transfer obligations pursuant to the agreements, IID and its farmers must conserve 303,000 acre-feet of water per year by 2026.

In 2005, IID begin developing the Efficiency Conservation Definite Plan (ECDP) to identify a mix of on-farm actions, delivery system improvements and incentive packages that would conserve the water required. The ECDP was completed in early 2007 and provides the technical foundation for IID's Efficiency Conservation Program (ECP).

The ECP, initiated in 2008, implemented seepage interception systems, developed the on-farm efficiency conservation program and developed an integrated data management system to track and forecast the volumes of water conserved. Testing and refinement of the delivery system and farm delivery measurement improvements led to the System Conservation Plan (SCP) featuring reduction, recapture and re-use of spillage from IID laterals.

In 2010, IID completed Phase 1 of the Main Canal Decision Support System (MCDSS). The MCDSS supports IID's main canal water delivery scheduling and daily water accounting processes. Of key importance was the need to automate IID's long standing paper processes in a manner that eases the paper to computer transition for the main canal operators.

MCDSS OVERVIEW

The Main Canal Decision Support System (MCDSS) is an integrated collection of decision support tools designed to provide support to IID's Water Control Center (WCC) main canal operations. WCC decisions are of two types: flow scheduling and system operation (to achieve the scheduled flows). Scheduling decisions involve planning horizons ranging from a half-day to a year, while operation decisions are executed in real time, or within hours. The principal scheduling decisions involve: 1) determining the master water order for the District from the Colorado River (annual forecast, weekly forecast four days in advance, and daily finalization of tomorrow's order); 2) allocation of tomorrow's water to the IID Divisions by main canal sales area, and; 3) scheduling daily main canal (reservoirs, main canal headings, checks, etc.) and lateral heading flow changes. Most operation decisions are the result of unscheduled changes and operational error (lack of precision in gate settings and measurement error) during the day, requiring changes at main canal control points (reservoirs, main canal headings, checks, etc.) and lateral headings.

Version 1.0 of the MCDSS focuses on automation of the Daily Water Record (DWR) and scheduling of main canals, also referred to as the Main Canal Breakdown (MCB). The main objective for this version of the MCDSS is to provide main canal dispatchers (operators) with the information to support main canal scheduling decisions. In addition, supplying this information and performing required calculations through the MCDSS reduced errors and the time spent preparing the information to support scheduling decisions. The MCDSS provides more timely and accurate information for operational decisions, ultimately supporting IID's water conservation goals. To ensure the success of the automation process, two important additional goals were to ease the transition from paper to computer and to enhance dispatcher confidence in the new tools. These two goals were accomplished by designing the application interface in close cooperation with the dispatchers with a look similar to paper forms to which they were accustomed. Table

1 lists WCC scheduling and operations decisions, respectively, supported by Version 1.0 of the MCDSS.

Table 1. WCC Scheduling Decisions Supported by MCDSS v1.0

Decision	Cause for Decision	DSS Development Phase
Schedule changes at lateral headings	Changes in water orders from previous day	Phase I
Schedule main canal flow changes (reservoirs, main canal headings, checks, etc.)	Changes in water orders from previous day	Phase I
Schedule changes in response to 12-hour order changes	Changes in water orders due to 12-hour order changes	Phase I

Daily Water Record (DWR)

The DWR forms the basis for the daily scheduling and operation of IID's main canal system. All lateral heading and direct delivery orders and deliveries are entered on the DWR and main canal operations planned accordingly. Automation of the DWR and the associated main canal breakdowns is the core of the MCDSS.

In its paper form, the DWR, also called the "desk sheet," was a large format, hand-entered, daily water ledger of flows for IID's main canal system. The DWR within the MCDSS preserves the same functionality and basic structure of the paper version. The DWR screen displays rows for each lateral heading and main canal direct delivery. Lateral headings and main canal direct deliveries (main canal deliveries) are grouped into delivery areas corresponding to MCB points. For each lateral heading and main canal direct delivery there is an entry for the ordered water for the day (24-hour deliveries) and the A.M. and P.M. deliveries (12-hour morning and afternoon deliveries, respectively). In addition, all actual delivery rate changes and the time they occurred are recorded and averaged to determine the mean daily delivery rate.

The water order and flow data stored on the DWR serve as a database for the IID water distribution system and are used for two main functions. First, water flow data are used in various reports to document where water is used within IID. Second, the water order totals at these main canal system control and delivery points are utilized to schedule flow changes throughout the distribution system to ensure that all water order requests are fulfilled. This function is completed by transferring these totals to the MCB, which, prior to the MCDSS, was a manual process involving a second set of paper forms.

Prior to the MCDSS, three DWR sheets (TOMORROW, TODAY, and YESTERDAY) were used to develop the schedule of daily flow changes. Lateral heading orders for the following day, plus required operational water, were aggregated by IID's Water Order Entry (WOE) system by summing the orders on each lateral scheduled to run tomorrow plus required operational water. These lateral heading orders were then hand-entered into the Ordered column of the TOMORROW DWR sheet. Morning and afternoon flows and deliveries reported by IID field staff and SCADA were written on the TODAY DWR sheet in the A.M. and P.M. columns. The differences between today's flows and tomorrow's orders together with today's computed losses and reservoir trends, formed the basis for the MCB, used to schedule main canal flow changes. Final accounting calculations were completed in the YESTERDAY DWR sheet, once morning flows reported by IID field staff were written on the TODAY DWR sheet and deliveries were complete and entered into the WOE system. Selected data from the DWR were then used for various reports and to develop the Master Water Order.

Main Canal Breakdown (MCB)

The MCB divides the main canal into operational reaches, starting at the downstream end, and working upstream. In this manner, scheduled changes for downstream reaches are incorporated into the planned changes for upstream reaches. The water order totals and current flows at various main canal system control and delivery points from TOMORROW and TODAY DWR sheets were utilized to schedule flow changes throughout the distribution system. These totals were transferred to various MCB paper sheets that, together with information on reservoir storage and return to system flows, provided the dispatcher with all the information required to schedule flow changes at the various main canal control points. MCB sheets were linked by writing the summations of flows at the head of downstream breakdowns in the next upstream MCB.

Reports

Both the DWR and MCB include task critical reports that could be executed directly from these applications. Additional reports identified through a series of workshops with Water Department staff are included with the MCDSS and can be executed from the MCDSS.

AUTOMATION OF THE DWR AND MCB

Increasing amounts of the information that was hand-entered on the DWR sheets is digital data from IID's WOE, SCADA, and the Water Information System (WIS) computer systems. Because the DWR is at the center of WCC operations, development of the MCDSS had to begin there. Manually entering information not already in digital form into a computer system provided the basis for computer-calculation of sums by MCB reach, thereby reducing errors and saving time. This provides the dispatchers with more time to concentrate on making the correct operational decisions. Automation of the DWR and MCB also provides a foundation supporting scheduling and operations closer to real-time.

The primary data sources for the automated DWR are the same as for the manual DWR: (1) the WOE system for all customer orders and deliveries and (2) either SCADA or manual entry of field measurements for all main canal control points (reservoirs, main canal headings, checks, etc.), lateral headings, and direct deliveries. In the automated DWR, all data for the DWR flow directly to the WIS where queries aggregate data by control point and lateral heading and store results in keyed and time stamped tables (Figure 2). Once the dispatchers gain confidence and experience in the new computer environment, their suggestions will be incorporated in the next version of the MCDSS further enhancing their productivity.

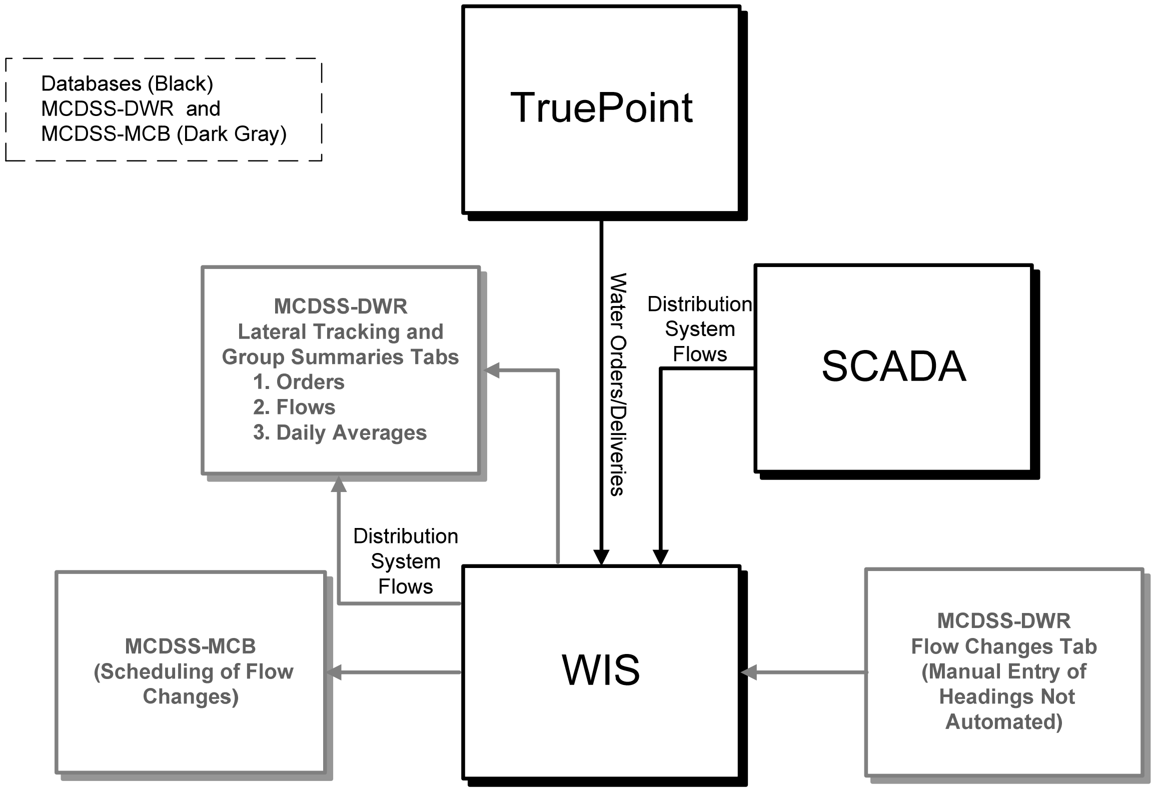

Figure 2. Schematic of Data Flow in the MCDSS

MCDSS-DWR Development

As the core of the MCDSS, the DWR Human Machine Interface (HMI) was developed first as four tabs. The *Flow Change* tab (Figure 3) is used for manual entry of all orders and flows not yet available through the SCADA system. The *Lateral Tracking* tab (Figures 4a, 4b and 4c) serves as the HMI for viewing the selected DWR sheet. The *Group Summaries* tab (Figure 5) was developed to display the various DWR totals. These totals are sums of more than one flow measurement location serving various accounting functions. Certain parameter settings in the MCDSS – DWR can be changed by the user, via the *Maintenance* tab. The MCDSS – DWR was tested and validated for two months prior to the initiating testing of the MCB prototype spreadsheet described in the following section.

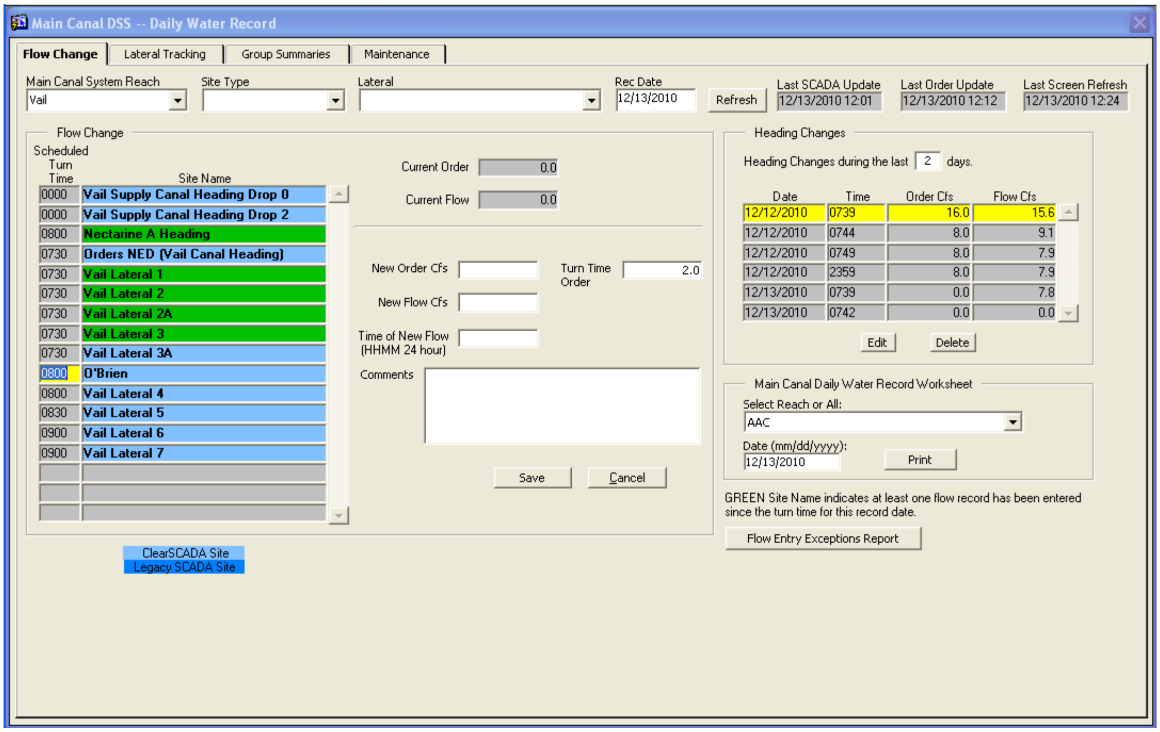

Figure 3. MCDSS-DWR Flow Change tab

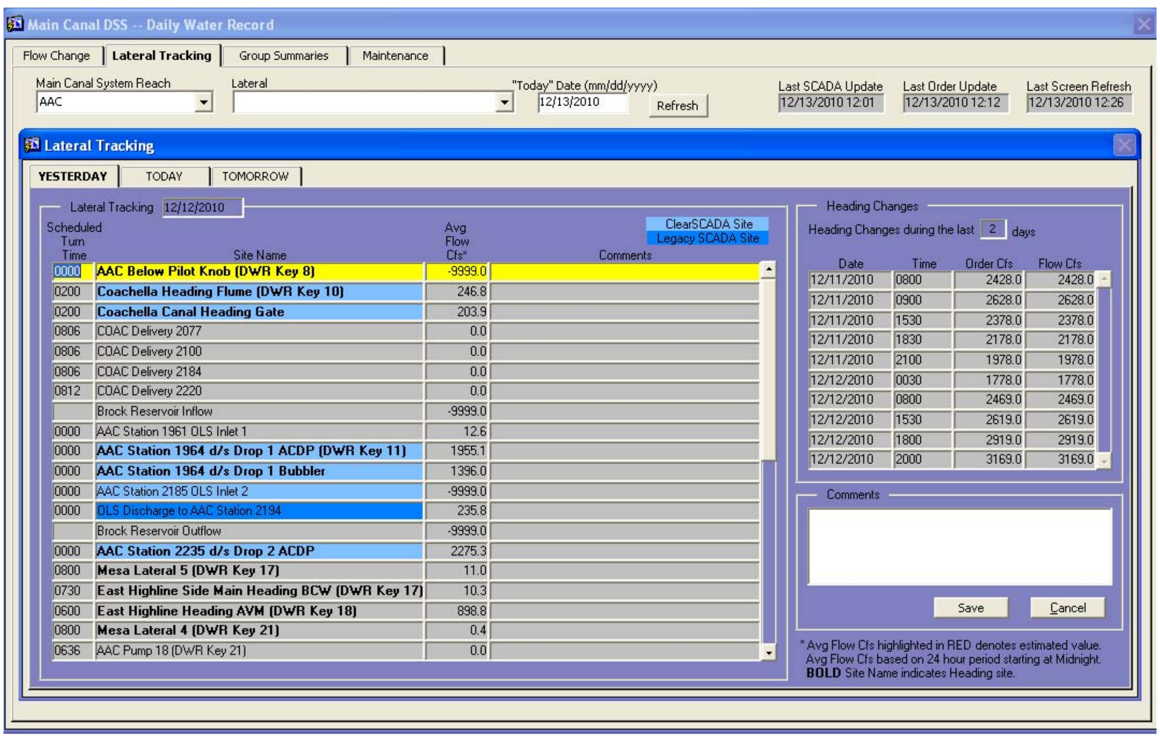

Figure 4a. MCDSS-DWR Lateral Tracking - Yesterday's Data

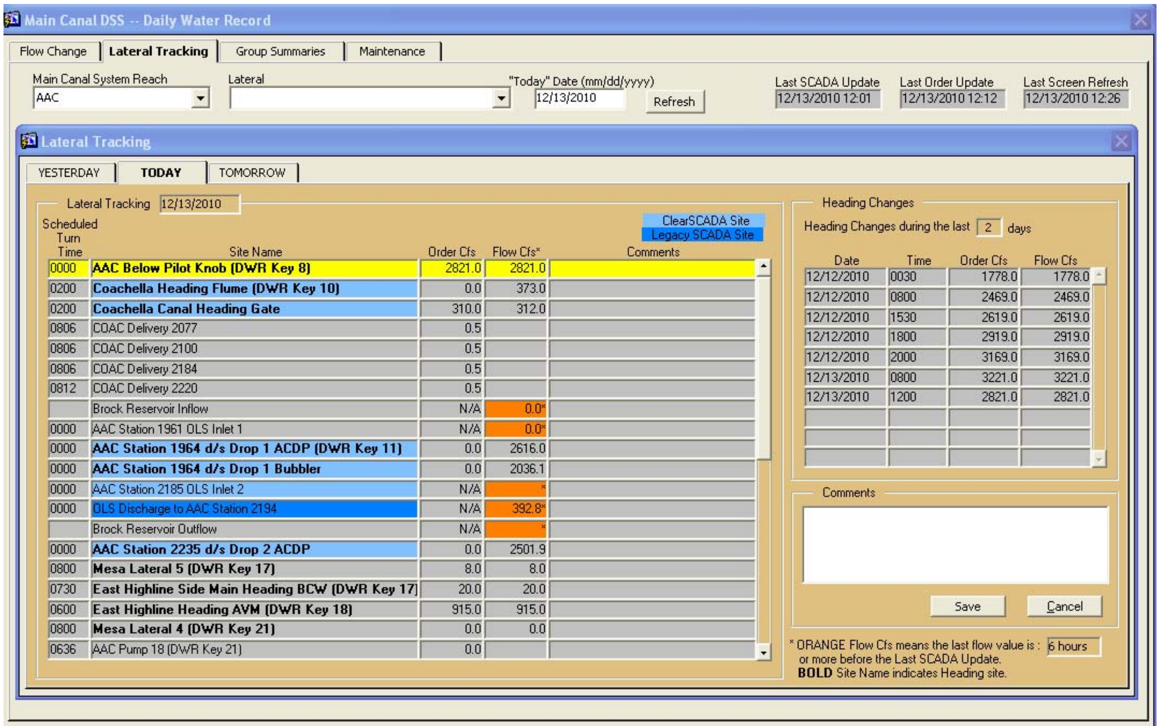

Figure 4b. MCDSS-DWR Lateral Tracking - Today's Data

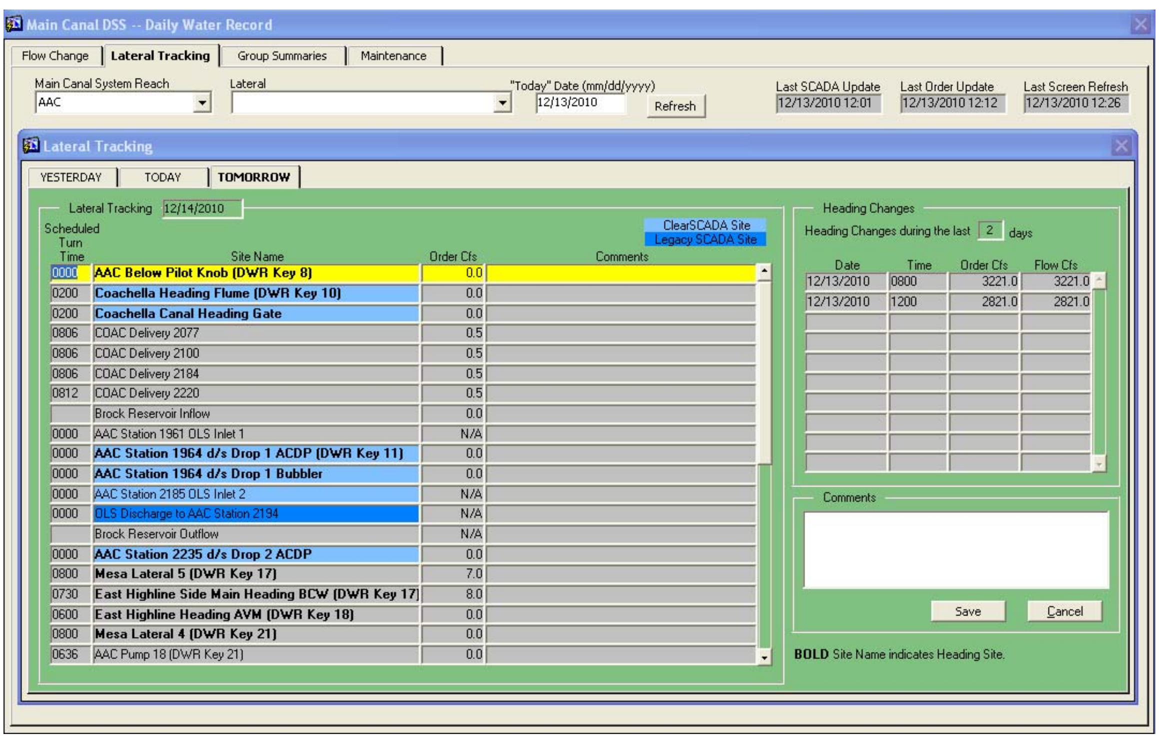

Figure 4c. MCDSS-DWR Lateral Tracking - Tomorrow's Data

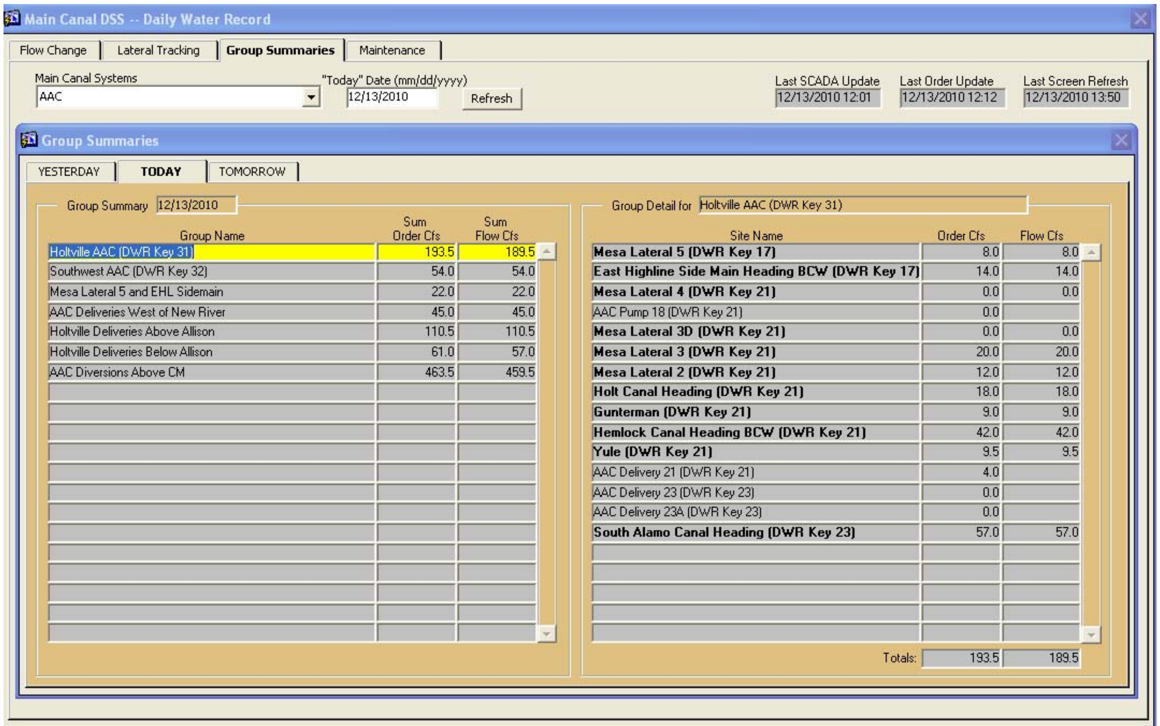

Figure 5. MCDSS-DWR Group Summaries - Today's Data

MCDSS-MCB Development

Automation of the MCB was prototyped in an Excel spreadsheet and then ported to the WIS after functionality testing was completed. The spreadsheet had all the functions needed to complete the Main Canal Breakdown and was linked to the WIS through an MSAccess database. This linkage imported to the spreadsheet all data manually entered through the automated MCDSS-DWR and transferred to the WIS from the WOE and SCADA systems. To enhance dispatcher confidence in the MCB and ease the transition to the new system, the groupings in each MCB area remained the same as in the paper system. The only difference from the paper sheets was the introduction of the 12-hour main canal breakdown analysis[5]. This additional breakdown provides information that enhances the scheduling of afternoon changes resulting from 12-hour deliveries. This was made possible with the MCDSS automation of the DWR. The order type in the WOE system provides the information to separate AM and PM orders.

Following one month of functionality testing of the spreadsheet, the validated functionality was developed on the WIS. The Main Canal Breakdown (MCB) consists of two tabs: the *ORDERS*

[5] 12-hour deliveries were introduced to IID as a component of the Metropolitan Water District transfer agreement. Generally the total volume of daytime (AM) 12-hour deliveries exceeds the nighttime (PM) 12-hour deliveries. Water is ordered to meet the AM requirement and the excess water in the PM is stored in-line and in reservoirs. Before the MCDSS, the change in deliveries and canal flow between AM and PM was seen as change in system gain or loss. The MCDSS automation will allow explicit AM and PM scheduling.

tab and the *MCB* tab. The *ORDERS* tab (Figure 6) provides an entry screen for entering orders not available in IID's WOE software. Under the *MCB* tab, the main canal system is divided into

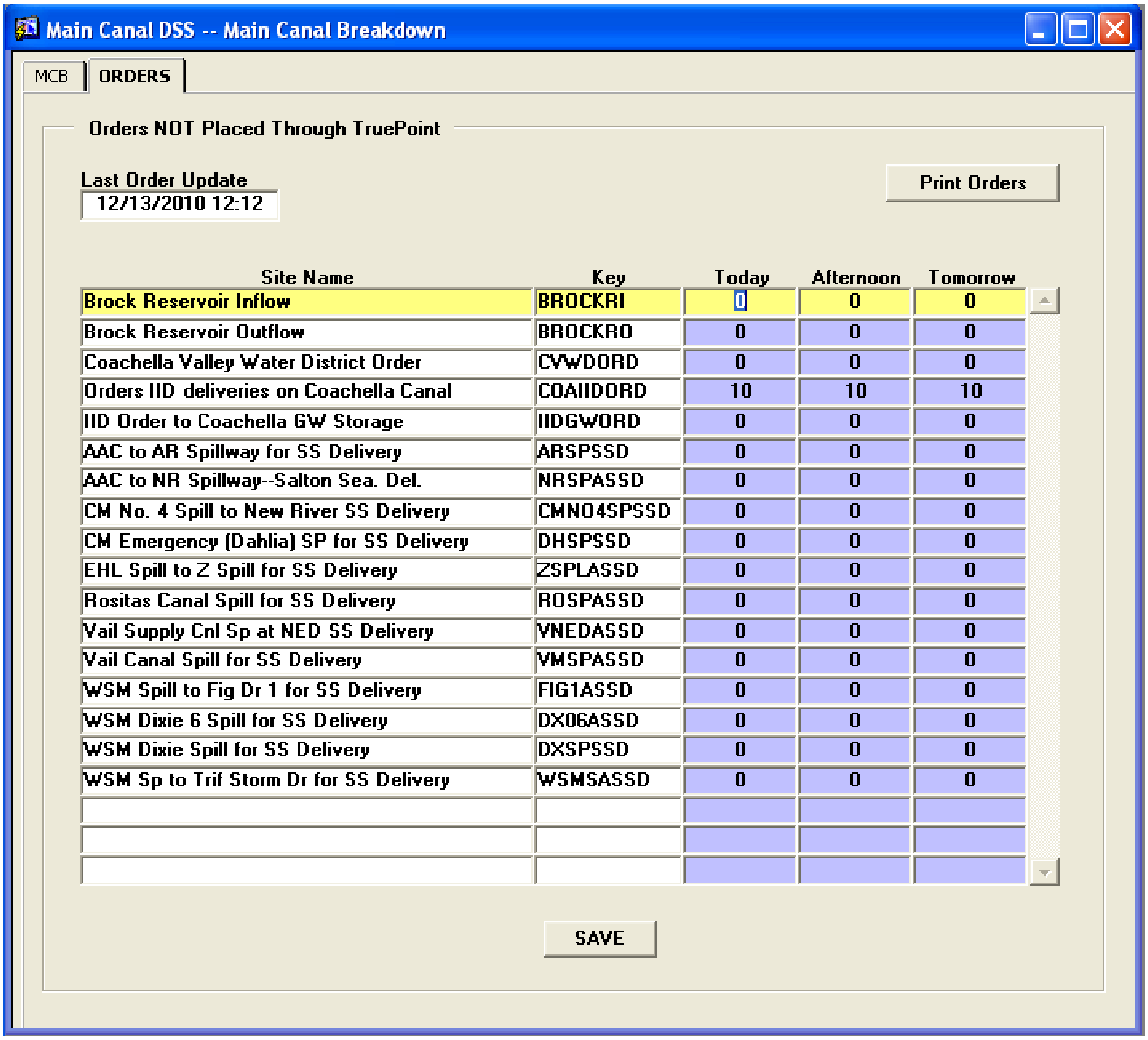

Figure 6. MCDSS-MCB Orders Tab

17 reaches (Table 2). Each reach begins at a control point where flow changes are scheduled. The screen is organized the same for each main canal control point, but different data is retrieved and displayed depending on the selected MCB reach. Many, but not all, of these control points have some storage available. Each reach below the control points is further broken down into groups of lateral and main canal outflows. A single flow change at the reach control point will supply water to the groups of laterals and main canal outflows below that control point at the correct time to serve customers. The Dispatcher can select each control point and corresponding reach breakdowns to schedule flow changes in response to order changes for the afternoon and tomorrow.

Table 2. IID Main Canal Breakdown by Reach in the MCB

No.	Reach Name	No.	Reach Name
1	Westside Main Below No. 8 Heading MCB	10	East Highline Below Nectarine MCB
2	Westside Main All MCB	11	East Highline All MCB
3	Central Main Below No. 4 MCB	12	Briar Old MCB
4	Central Main Below Dahlia MCB	13	Briar All MCB
5	Central Main All MCB	14	All American Canal Below Central Check MCB
6	Vail below NED MCB	15	All American Canal Below Drop 2 to Central Check MCB
7	Vail Supply Canal MCB	16	Coachella Canal MCB
8	Redwood Canal MCB	17	All American Canal from Pilot Knob to Drop 2 MCB
9	Rositas MCB		

The *MCB* tab (Figure 7) consists of six sections. Dispatchers can enter data into cells with a light blue background. Reductions in flow are displayed in red font and enclosed in brackets. The *Reach* section allows the Dispatcher to select the MCB reach and provides information about the timing of the available data. The *Canal Reach* section "breaks down" the reach into groups of orders. The *Schedule Changes* section is where the Dispatcher enters the flow change amounts and the scheduled time to make the flow change. The *Reservoirs* section provides information on storage volumes and storage volume trends in the reservoirs which can contribute supply to the reach. The *Flows* section provides information about the flow passing selected checks today and the expected flow passing those checks tomorrow. The *RTS* section provides information on flows that are returned to the system in the selected reach. These flows may be from a reservoir in the reach or from the end of a canal that flows into the reach.

The MCDSS - MCB was tested for one month, and following correction of all errors noted, IID staff began using the MCDSS on November 1, 2010. The last date for the paper DWR and MCB forms was October 31, 2010. The prototype spreadsheet was modified to serve as an emergency MCB backup with manual data entry.

WIS Code and Structures Required

Six scripts, 15 procedures and 10 functions assemble data from 17 tables in the MCDSS. All code and required data is stored in the WIS Oracle database at IID. The computer code comprising the applications is stored in the WIS Oracle database.

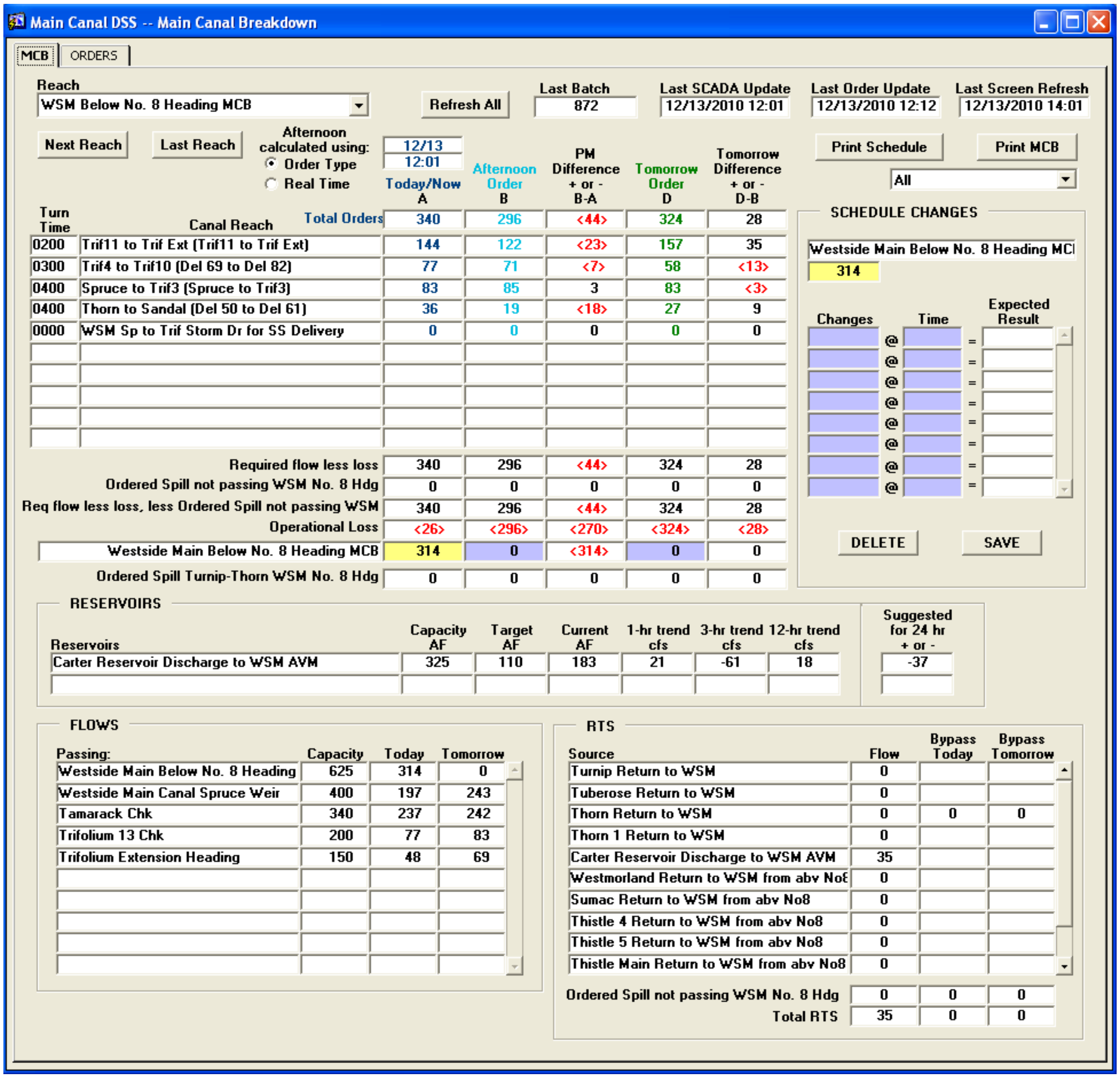

Figure 7. MCDSS-MCB MCB Tab

CONCLUSION

IID has been using the MCDSS since November 1, 2010. The MCDSS has achieved the two main objectives of providing better and more timely information on which to base operational decisions. The MCDSS development process eased the transition from paper to computer and enhanced staff confidence in the new tools by designing the application interface in close cooperation with the dispatchers and remaining consistent with the paper forms that they were accustomed to. The MCDSS provides IID with a framework to build upon. As staff continues to use the system, their suggestions for improvements and enhancements will be included in the next phase and additional decision support tools beyond presenting information will be incorporated.

EVALUATION OF FLOW MEASUREMENT SITES ON THE NORTH PLATTE RIVER NEAR THE WYOMING-NEBRASKA STATE LINE

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ABSTRACT

The State Line Gage Subcommittee (SLGS) of the North Platte Decree Committee (NPDC) assembled a project team to evaluate the existing flow measurement sites on the North Platte River in the vicinity of the Wyoming-Nebraska State Line. The team was tasked to provide analysis and evaluation regarding the hydraulic characteristics at each site, as well as recommendations to improve the stability and accuracy of flow measurements made at each site.

The team evaluated several sites including the State Line flow monitoring site, the Tri-State Canal Replogle flume, and the Passing Tri-State flow monitoring site. The State Line flow monitoring site is a key flow measurement point in the allocation of the natural flow of the North Platte River between water users in Wyoming and Nebraska. Currently, discrepancies in discharge measurements at the three sites complicate the administration of the Settlement and storage deliveries. The project aimed to evaluate the existing hydraulic characteristics at each site and to recommend improvements that would increase the stability of the rating curve and the accuracy of flow measurements. In addition to the site assessment, a mass balance relationship between the three sites was developed. The mass balance analysis included a review of the last 5 years of data for each of the sites and an evaluation of all relevant terms in the study reach.

INTRODUCTION

Aqua Engineering, Inc. and WEST Consultants, Inc. were selected by the State Line Gage Subcommittee (SLGS) of the North Platte Decree Committee (NPDC) to evaluate the existing flow measurement sites on the North Platte River in the vicinity of the Wyoming-Nebraska State Line. The three sites are: 1) the State Line Flow Monitoring Site, 2) the Tri-State Canal Replogle flume, and 3) the Passing Tri-State flow monitoring site. The project team evaluated the hydraulic characteristics of each site and recommended structural modifications to improve the stability and accuracy of flow measurements (Figure 1). In addition, the mass balance relationship between the three sites was evaluated through a review of the previous 5 years of data.

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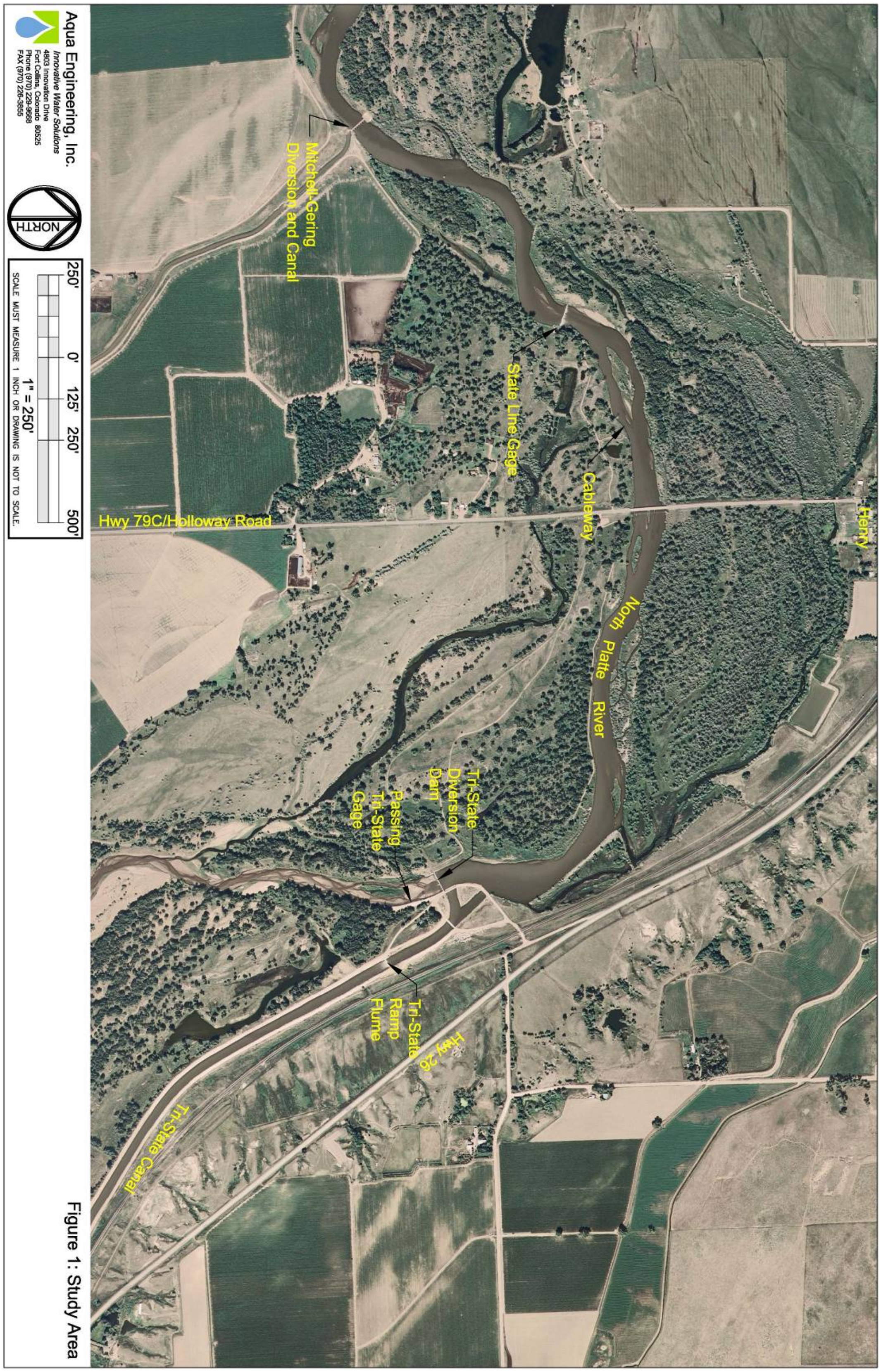

Figure 1. Project Study Area

STATE LINE SITE

The State Line flow monitoring site (State Line site) is located on the North Platte River in Goshen County, Wyoming. It is located at the site of the original Gering Diversion Dam that washed out in 1957. The structure was built in 1994 and consists of a sheet piling driven into the river bed, downstream gabion channel and bank protection, and associated water level monitoring instruments and telemetry devices contained in a masonry gage house located adjoining the site (see Figure **2** and Figure **3**). The structure has a V-shaped notch located near the south bank of the North Platte River that passes low flow events. The structure is toed-down 20 feet in the main channel and 10 feet on the banks. Gabions were installed upstream and downstream to protect against scour. The present State Line site replaced an earlier gage location, located approximately 1,400 feet downstream of the present State Line site.

The State Line site is the key flow measurement point in the allocation of the natural flow of the North Platte River between water users in Wyoming and Nebraska, pursuant to the requirements of the *Nebraska v. Wyoming* Settlement. It has a further role in the measurement of storage water delivered by the United States Bureau of Reclamation (USBR) from Guernsey Reservoir in Wyoming to storage contract holders in Nebraska. A stage-discharge relationship has been established for the control, which is checked and adjusted with frequent current-metering discharge measurements. A dike on the north side of the North Platte River, approximately 585 feet upstream of the control, prevents water from traveling down a slough on the north bank of the river and bypassing the State Line site.

Figure 2. State Line Site

Figure 3. Close up of Sheet Piling Weir at the State Line

The North Platte River is a sand channel at the State Line site. A large sand bar is located upstream of the control, near the north bank (see Figure **4**). The south bank of the North Platte River is covered with thick grassy vegetation and, recently, has been eroding severely. The State Line site is located just downstream of a bend in the river. Rantz (1982) recommends at least 300 feet of straight channel upstream of the flow measurement location. For the State Line site, there are only about 100 feet of straight channel upstream of the control. The gage house and equipment is located on the south bank (i.e., on the outside of the bend) near the control. This setup allows the gage to operate during low flows because the stage measurement equipment accesses the deepest part of the river. Currently, the gage house and equipment are threatened by erosion on the south bank upstream of the control (see Figure **5**).

Figure 4. Sand Bar Upstream of State Line Gage

Figure 5. Severe Erosion near State Line Gage

Flows at the State Line are measured using frequent current-meter discharge measurements. On days that current-meter discharge measurements are not performed, flow is estimated using a shift-corrected stage-discharge relationship. The procedures and methodologies utilized to perform a flow measurement appear to be consistent with typical practices (e.g., see Rantz (1982)). An analysis was performed to estimate the uncertainty associated with the current-meter discharge measurements and the computed flow estimates (i.e., flow values determined from the shift-corrected stage-discharge relationship). Using data from 2008, the average uncertainty for a current-meter discharge measurement was estimated to be 6.5% while the uncertainty of the computed flow estimates was estimated to be 6.8%. The uncertainty analysis indicated that applying a correctional shift is appropriate for the State Line site.

A geomorphic analysis was also performed on the State Line site. This analysis indicated that the site was relatively stable until 2006. Thereafter, severe erosion has occurred upstream of the control along the south bank. In addition, a large sand bar has formed near the north bank, immediately upstream of the control. The most promising mitigation technique for stabilizing the State Line site may be the installation of bendway weirs upstream of the control structure. Bendway weirs have the following benefits:

- Scour will be reduced along the south bank of the North Platte River.
- Sedimentation will occur near the weirs.
- The main flow path will be moved away from the south bank, more towards the center of the channel.
- The re-directed flow will have a tendency to scour the large sand bar near the north bank of the river.
- The sediment that deposits near the weirs will not be able to deposit on the sand bar.
- The improved stability of the site could reduce the amount of shifts needed for the stage-discharge relationship.

TRI-STATE CANAL RAMP FLUME

The Tri-State Canal Replogle flume is located in the Tri-State Canal approximately 1,000 feet downstream of the Tri-State Canal diversion dam (see Figure **6**). The site is located in Scotts Bluff County, Nebraska. The structure was constructed in 2003 by the Farmer's Irrigation District (operator of the Tri-State Canal and appurtenant structures) and replaced a cableway and current meter discharge measurement system. The Replogle flume design and specifications were prepared by the Natural Resources Conservation Service (NRCS), and the site also includes water level monitoring instruments and telemetry devices housed in a gage house adjacent to the flume. An existing cableway is located upstream of the Replogle flume which previously served as the flow measurement location for this canal. Presently, this site serves no official role in the allocation of natural flows in the North Platte River, as the official point of diversion for the Tri-State canal is at the State Line site, located approximately 6,800 feet upstream of the canal diversion.

In the past, the Tri-State diversion was measured as a part of the determination of the flows at the state line in accordance with the terms of the North Platte Decree. Since construction of the State Line site, it no longer is used to determine water deliveries under the North Platte Decree. Allocation rules under the Decree indicate that the water users diverting at the Tri-State Canal have their diversion measured at the State Line site, and these data are subsequently used by the State of Nebraska to develop official diversion records for the canal.

Currently, the Replogle flume provides flow data to assist the operation of the canal, for the benefit of the Tri-State Canal users. Construction of the flume was partially funded by the USBR. The USBR maintains satellite telemetry equipment at the flume and the data is recorded on the HydroMet system. Tri-State Canal water users are senior water rights holders and typically divert most of the natural streamflow entering Nebraska. Further, they hold storage contracts with the USBR that entitles them to delivery of storage water from USBR facilities located upstream.

The Tri-State Canal Replogle flume appears to be a stable, accurate flow measurement structure. The existing structure has a number of variances from the design drawings, but these departures are consistent with the hydraulic requirements and limitations of Replogle flumes and the rating curve should simply be adjusted to incorporate these changes. The following recommendations for improvements are offered:

- Adopt the updated rating curve which reflects the as-built flume geometry.
- Miter the stilling well intake to match the concrete wall.
- Reset the shaft encoder float and counterweight such that the counterweight is not submerged.
- Adjust the outside chain gage so that it matches the location of the stilling well intake.
- Install concrete key-ins and toe down (if needed) to tie the flume to the canal banks and prevent canal sloughing from undermining the flume.

- Remove algae buildup from the flume sill in the off season, as-needed.

Figure 6. Replogle Flume on the Tri-State Canal

PASSING TRI-STATE

The Passing Tri-State flow monitoring site (Passing Tri-State site) is located in Scotts Bluff County, Nebraska. The site is located approximately 450 feet downstream of the Tri-State Canal Diversion Dam (see Figure **7**) and includes water level monitoring instruments, but no control.

Prior to construction of the State Line site, the Passing Tri-State site was used in conjunction with the Tri-State Canal diversion to determine the natural flow at the state line and, thus, to administer the allocation of the natural flows in the North Platte River. Since construction of the State Line site, the Passing Tri-State measurement is used by the State of Nebraska to administer irrigation deliveries to water rights holders located downstream of the Tri-State Canal. Official records for discharges are maintained by the State of Nebraska through 1996. After 1996, Nebraska maintains only provisional discharge data used in the accounting and administration of water use on the North Platte River.

The Passing Tri-State site is an uncontrolled stream gage in a shifting, sand bed channel. As a result, annual channelization is required to eliminate the braided channel morphology and force flows through the channel in the vicinity of the bubble gage (see Figure **8**). Frequent current meter discharge measurements are required to establish and check the annually-derived rating curve. The gage installation and operations are adequate, but the overall approach is significantly less accurate than discharge measurements made at the other sites included in the study. The following recommendations for improvement are offered:

- It may be possible to establish better flow measurement through the calibration of a single radial gate in the Tri-State diversion dam, or use of a theoretical discharge equation. Implementation of this approach is the least costly, but is subject to negotiations with Farmer's Irrigation District and potentially altering the current gate operations scheme.
- The next least-costly option is installation of a Replogle flume in the Tri-State bypass channel, located approximately one mile downstream of the Tri-State ramp flume. This option is the least costly structural alternative.
- Establishment of a control at or near the current gaging site may be problematic both technically and from a regulatory perspective, and should be avoided.
- If none of the above three options is feasible, the existing approach should be maintained and current meter discharge measurements should be made as often as is practical.

Figure 7. Passing Tri-State Canal Diversion Dam

Figure 8. Bubbler System on the Passing Tri-State Site

MASS BALANCE RELATIONSHIP

The mass balance between the three sites was evaluated for the period between September 2003 and September 2008. The goal of the analysis was to quantify gains and losses that may occur in the reach and explain disparities between the measured flows at the three subject sites. Factors that affect the mass balance in the study reach include:

- Discharge at State Line site (Q_{SL}), measured on a daily basis.
- Discharge at Tri-State Canal (Q_{TS}), measured on a daily basis.
- Discharge at Passing Tri-State site (Q_{PTS}), measured on a daily basis.
- Unmeasured discharge at Spring Creek (Q_{SC}) , estimated at an average of 7 cfs and assumed to occur year-round.
- Unmeasured discharge at North Drainage (Q_{ND}) . This flow is observed on the aerial photography, but was not observed in the field. This may be episodic or seasonal seepage from the alluvial aquifer that bypasses the State Line site and enters the North Platte River above the Tri-State Canal diversion.
- Unmeasured discharge at Centennial Creek (Q_{CC}). This inflow has not been considered in previous evaluations of this reach. Centennial Creek is a relict braid of the North Platte River (Stateline Island National Wildlife Refuge) which reenters the river downstream of the Tri-State Canal diversion, and flow conveyed in this watercourse emanates from the North Platte River alluvial aquifer.
- Precipitation and runoff from the local drainage area (Q_{RO}). Precipitation is measured on a daily basis, but runoff from the local drainage area is not measured.
- Evaporation from the free water surface and evapotranspiration from phreatophytic vegetation in the reach (Q_{ET}). These terms are not measured.
- Seepage to or from the local alluvium is not measured (Q_S).
- Change in storage behind the Tri-State Canal diversion dam ($Q_{Storage}$). This is measured by Farmer's Irrigation District, but the data is used operationally and is not stored or available.

A complete, detailed mass balance could not be conducted at this time due to the lack of data for several factors. Thus, the analysis was simplified to include only those terms that are measured or a reasonably or customarily estimated (i.e., Spring Creek inflow).

The hydrograph analysis showed that the combined measurement uncertainty for each site can explain most differences in the mass balance. Spikes and troughs in the hydrograph are typically associated with anomalous discharges at the Passing Tri-State site. A partial mass balance, based on the primary mass balance components, yielded residuals which did not appear to indicate a bias toward known factors which may contribute to the observed discrepancy. The largest potential contributors to mass balance discrepancy in the study reach are as follows:

- Measurement uncertainty at the sites.
- Change in storage in the Tri-State pond.
- Discharges into or out of the study reach by tributary watercourses.

Measurement uncertainty at each site was defined as a part of this study. The change in storage and the tributary discharges can be measured and recorded at each site, if desired. It may be useful to collect the additional data and complete a mass balance over the course of an irrigation season to assess the effect of pond storage on the apparent discharge discrepancy.

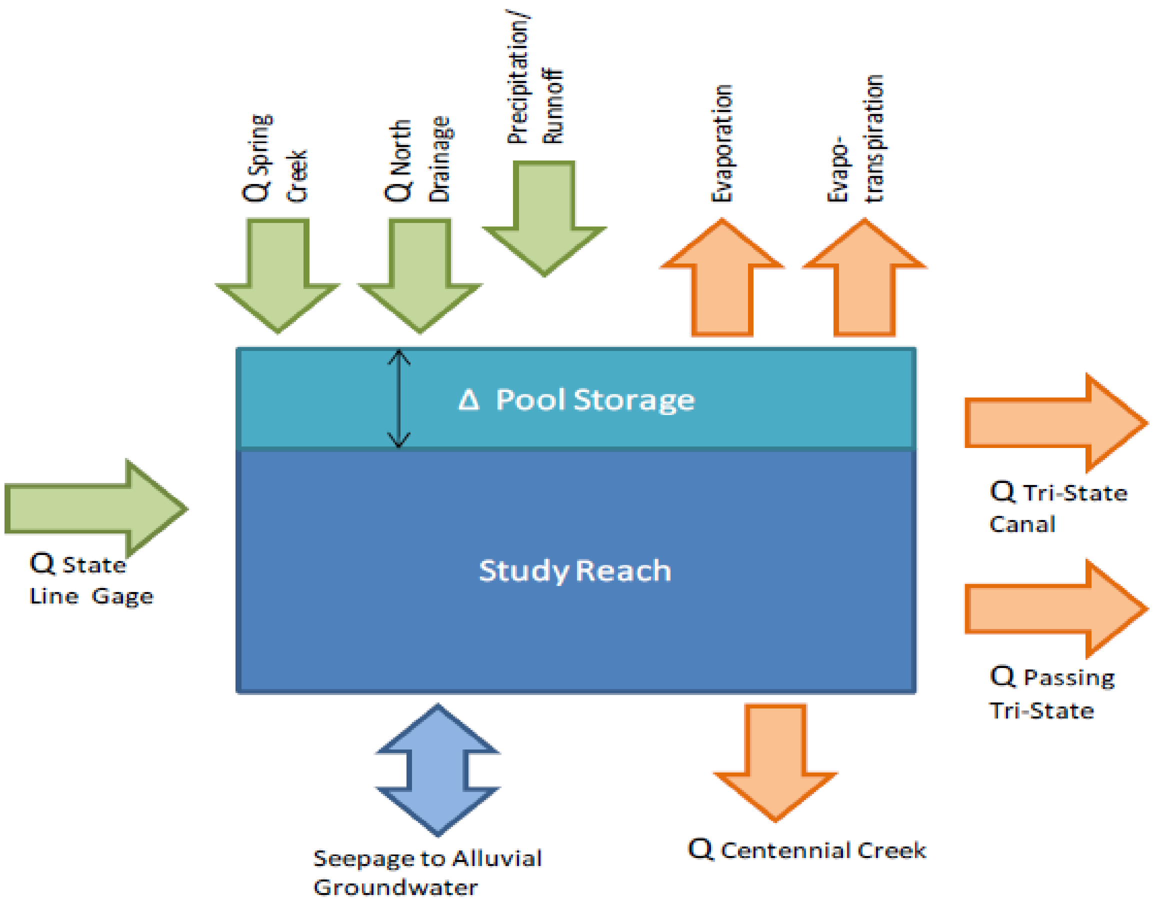

Figure 9. Mass Balance Schematic

CONCLUSIONS

Three different flow measurement sites were evaluated as part of this study. Recommendations were made for each of the three sites. The most pressing issue for all three sites was the unstable bank near the gaging equipment for the State-Line Site. This instability has the potential to destroy the State-Line Site if no remediation efforts are taken. Currently, the NPDC is designing a series of bendway weirs that will be installed in an attempt to stabilize the bank.

The mass balance was of limited usefulness due to the number of uncertainties in the measurements. The biggest uncertainty was the lack of bathymetric information for the pool upstream of the Passing Tri-State Canal Diversion Dam. Obtaining this information would better define the mass balance relationship and would lead to a better understanding of the hydraulics of the overall system. If additional data collection efforts are implemented, it may be possible to complete a detailed mass balance for the study reach in the future.

REFERENCES

Rantz, S.E. (1982). *Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge.* USGS Water Supply Paper 2175, U.S. Government Printing Office, Washington, D.C.

COMPARISON BETWEEN SBX7-7 AND ORIFICE MEASUREMENT METHODOLOGY AT THE FARM-GATE LEVEL

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ABSTRACT

As part of a program to improve upstream water level water control and farm delivery steadiness, Reclamation District No. 108 (RD 108, District) recently replaced certain existing weir board check structures in selected District laterals with long crested weirs. The existing weir board checks had been used by operators for flow measurement, including estimation of farm delivery flows by computing differences between flows at checks upstream and downstream of farm delivery gates. After reviewing several options to provide an alternative means of farm delivery measurement with the existing structures removed and new long-crested weirs installed, the District selected a hybrid approach featuring direct measurement at individual farm delivery gates complemented by Acoustic Doppler measurements at key locations in the canal system. As part of its evaluation, the District conducted 60 verification flow measurements at existing farm delivery gates during the 2008 and 2009 irrigation seasons. The gates had a submerged orifice configuration and ranged from 18 to 48 inches in diameter. Farm delivery gate measurement errors were computed regarding the verification measurement as the standard. The errors were then compared to pending farm delivery measurement standards being developed by the California Department of Water Resources (CDWR). This paper describes the verification flow measurement procedure, summarizes the results of the error analysis and discusses implications relative to the pending CDWR regulations.

INTRODUCTION

As part of a program to improve upstream water level water control and farm delivery steadiness, Reclamation District No. 108 (RD 108, District) recently replaced certain existing weir board check structures in selected District laterals with long crested weirs (LCW). The existing weir board checks had been used by operators for flow measurement, including estimation of farm delivery flows by computing differences between flows at checks upstream and downstream of farm delivery gates. After reviewing several options to provide an alternative means of farm delivery measurement with the existing structures removed and new long-crested weirs installed, the District selected a hybrid approach featuring direct measurement at individual farm-gates

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complemented by Acoustic Doppler measurements at key locations in the canal system. As part of its evaluation, the District conducted 60 verification flow measurements at existing farm delivery gates during the 2008 and 2009 irrigation seasons. The gates had a submerged orifice configuration and ranged from 18 to 48 inches in diameter (Figure 1). The verification measurements were performed downstream of the farm delivery gate approximately at the location of Section A.

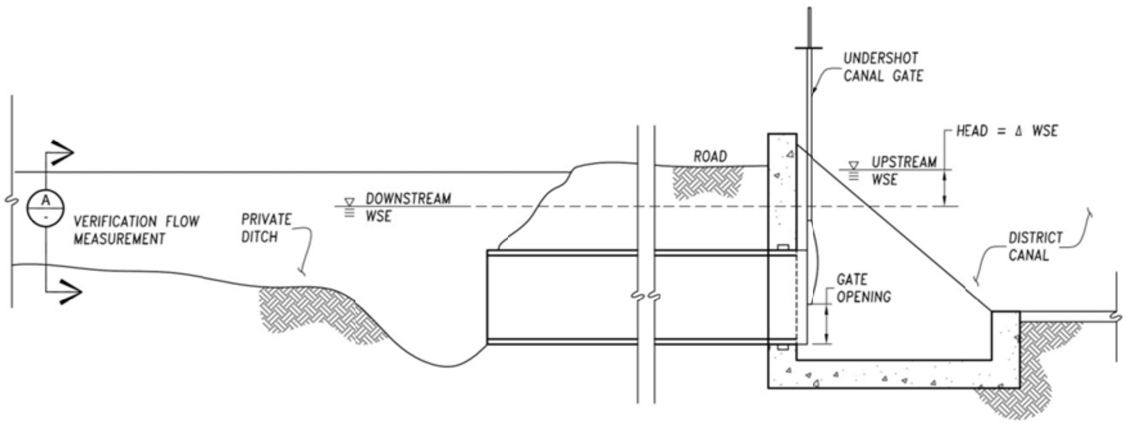

Figure 1. Typical Farm Delivery Cross-Section

FARM-GATE VERIFICATION FLOW MEASUREMENTS

Farm-gate verification flow measurements were performed by the conventional USGS mid-section current-meter method (Rantz 1982). Accordingly, the calculated discharge (Q) from a current-meter measurement is the sum of the products of the subsection areas (A) in a stream cross section and their respective average velocities (V) (Equation 1). Point velocity measurements used within the mid-section method were made by a SonTek FlowTracker Acoustic Doppler Velocimeter (Rehmel 2007). Due to limited water depths (generally less than 1.5 feet), the six-tenths-depth method was used to determine average velocity for each vertical subsection (Bureau of Reclamation 2001).

$$Q = \sum V * A \tag{1}$$

Figure 2 illustrates how station and depth information at incremental stations are used to determine A and Q for each location where V is measured.

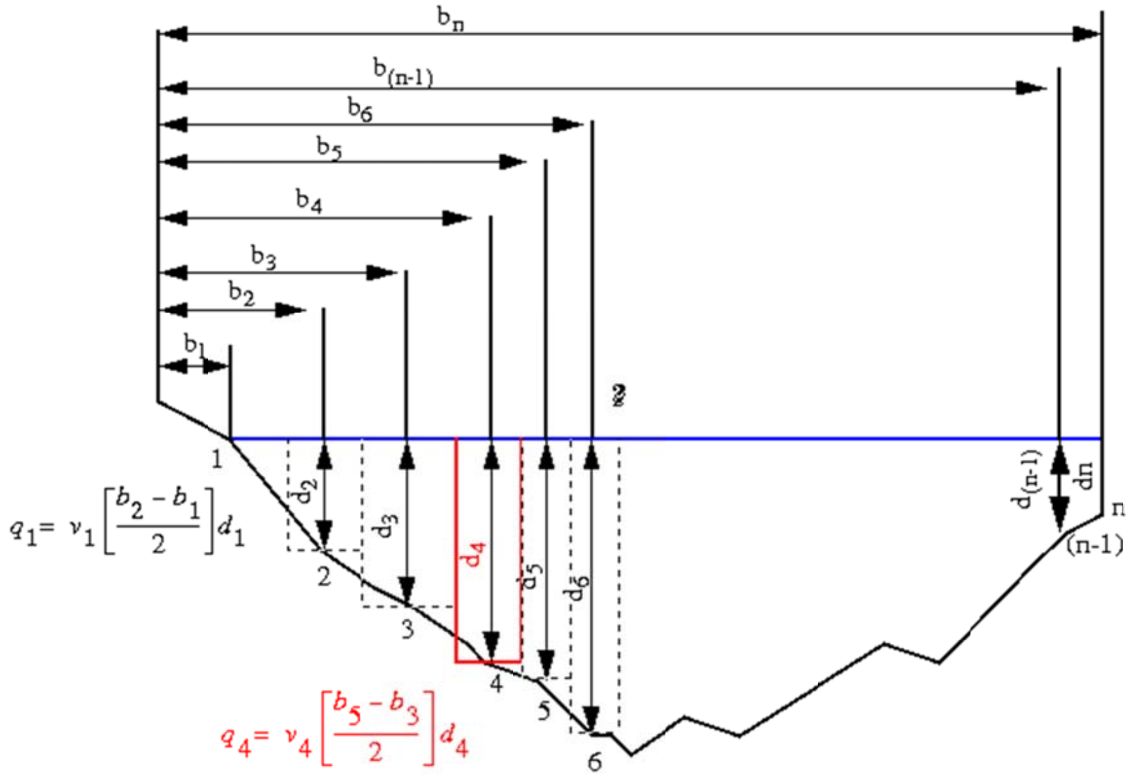

Figure 2. USGS Mid-Section Discharge Method (Rantz 1982)

Equation 2 was derived by combining Figure 2 and Equation 1, where x is the vertical station number, n is the total number of stations, b is perpendicular station and d is the water depth (Figure 3).

$$Q = \sum_{x=1}^{n} V_x * \left(\frac{b_{(x+1)} - b_{(x-1)}}{2}\right) * d_x \tag{2}$$

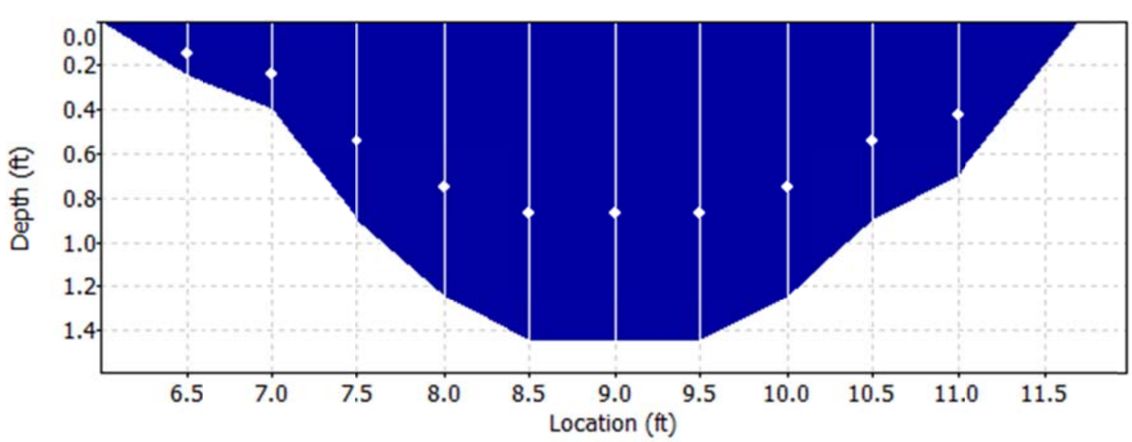

Figure 3. FlowTracker Cross Section for 121L Verification Measurement

The majority of verification flow measurements were performed in either concrete lined or earthen open channels (head ditches). Figure 4 illustrates flow measurement in a typical earthen head ditch, in this case with a maximum depth of 1.4 feet, top width of 6.7 feet and bottom width of 1.0 feet. Typically, velocity measurements were performed at 0.5 foot intervals with velocities averaged over a 40 second period.

Figure 4. Example Verification Measurement Setup

ORIFICE GATE FLOW MEASUREMENTS

Theoretical discharge through a submerged orifice can be solved from the Bernoulli Equation (Equation 3) where C is an empirical coefficient used to account for minor losses, flow contraction and velocity of approach (Bureau of Reclamation 2001), A is the cross section flow area, h is the headloss through the orifice and g is the gravitational constant.

$$Q = C * A * \sqrt{2 * g * h} \tag{3}$$

Information necessary for computation of discharge (i.e. cross section area and headloss) through orifice gates upstream of the verification measurement cross section was gathered at the beginning and ending of each verification flow measurement. Information gathered included the (1) site name, (2) date and time, (3) gate size, (4) gate type, (5) full-stem, (6) dead-stem, (7) upstream water surface elevation (WSE) and (8) downstream WSE. WSE upstream and downstream of the orifice gate was recorded at a minimum of before and after the verification flow measurement. As shown in Figure 5, stem measurements were performed from the highest part of the 'lift nut' to the top of the gate stem. Dead-stem was defined as the amount of stem at the onset of flow when moving the gate from a closed to open position. Full-stem was defined as the stem measurement during the verification flow measurement. A term representing the actual gate opening called “good-stem” was then defined as the difference between full-stem and dead-stem (Equation 4).

$$Goodstem = (Fullstem) - (Deadstem) \tag{4}$$

Figure 5. Dead-Stem and Full-Stem Measurements

Waterman gate rating tables provide flow rates through orifice gates as a function of gate opening (good-stem) and head loss (head) for each gate size (Figure 6). Implicit within these rating tables is the empirically derived orifice coefficient in Equation 3 above. These ‘factory’ rating tables generally assume standard conditions exist in the field including measurement of downstream water surface elevation one foot downstream of the gate. In most cases encountered during this investigation, there was no access to the downstream water surface elevation one foot downstream of the gate because the gates typically discharge into a 20- to 25-foot long culvert pipe crossing under a farm road before emptying into a head ditch. Instead, most downstream water surface elevation measurements were taken at the culvert discharge into the ditch. At low flows, this procedure does not pose a significant error because the friction loss in the culvert is negligible. However, at higher flows culvert friction loss becomes significant and could introduce error into the orifice gate flow calculation if not taken into account.

DISCHARGE DATA
24" WATERMAN RED TOP CANAL GATES WITH METERING WELLS- Model C-10

Head in Inches	Net Gate Opening In Inches (Discharge in Feet Per Second) 2	2½	3	3½	4	4½	5	5½	6	7	8	9	10	11
1	.71	.88	1.01	1.14	1.27	1.40	1.53	1.66	1.79	2.02	2.24	2.41	2.66	2.89
1¼	.80	.96	1.13	1.27	1.42	1.56	1.71	1.85	2.00	2.25	2.50	2.69	2.94	3.22
1½	.88	1.05	1.23	1.39	1.55	1.71	1.87	2.04	2.20	2.47	2.73	2.95	3.25	3.51
1¾	.95	1.14	1.34	1.56	1.69	1.86	2.04	2.21	2.38	2.68	2.97	3.11	3.49	3.80
2	1.00	1.22	1.43	1.61	1.79	1.98	2.17	2.35	2.53	2.84	3.15	3.40	3.74	4.07
2¼	1.07	1.29	1.52	1.72	1.91	2.10	2.30	2.49	2.68	3.02	3.35	3.62	3.96	4.31
2½	1.12	1.36	1.60	1.80	2.01	2.21	2.41	2.62	2.83	3.19	3.52	3.80	4.18	4.53
2¾	1.18	1.42	1.67	1.88	2.10	2.32	2.53	2.74	2.95	3.33	3.69	4.00	4.40	4.77
3	1.23	1.49	1.75	1.97	2.20	2.43	2.65	2.87	3.10	3.49	3.89	4.18	4.57	4.97
3¼	1.28	1.55	1.83	2.06	2.30	2.54	2.77	2.99	3.23	3.63	4.02	4.34	4.75	5.18
3½	1.33	1.61	1.89	2.14	2.38	2.62	2.87	3.11	3.35	3.78	4.19	4.51	4.92	5.35
3¾	1.38	1.67	1.96	2.21	2.47	2.72	2.97	3.22	3.48	3.91	4.32	4.67	5.11	5.53
4	1.42	1.72	2.02	2.28	2.55	2.79	3.03	3.31	3.59	4.02	4.45	4.82	5.29	5.73
4¼	1.47	1.77	2.08	2.35	2.63	2.85	3.08	3.39	3.70	4.08	4.60	4.99	5.44	5.90
4½	1.52	1.85	2.17	2.43	2.70	2.98	3.27	3.54	3.81	4.29	4.73	5.12	5.59	6.09
4¾	1.55	1.88	2.20	2.48	2.76	3.05	3.34	3.62	3.90	4.40	4.85	5.27	5.73	6.22
5	1.58	1.92	2.26	2.55	2.84	3.13	3.42	3.71	4.00	4.50	4.97	5.39	5.88	6.40
5½	1.67	2.02	2.37	2.67	2.98	3.28	3.58	3.88	4.18	4.62	5.21	5.65	6.18	6.71
6	1.74	2.10	2.47	2.79	3.10	3.42	3.75	4.06	4:38	4.95	5.48	5.90	6.44	7.00
6½	1.82	2.20	2.58	2.91	3.24	3.57	3.91	4.23	4.56	5.15	5.69	6.14	6.71	7.30
7	1.88	2.28	2.67	3.01	3.36	3.72	4.07	4.39	4.72	5.34	5.90	6.39	6.93	7.56
7½	1.95	2.35	2.76	3.06	3.49	3.85	4.21	4.56	4.92	5.55	6.12	6.60	7.20	7.82
8	2.02	2.43	2.85	3.19	3.60	3.96	4.33	4.70	5.08	5.71	6.30	6.80	7.45	8.07
8½	2.07	2.50	2.94	3.32	3.70	4.09	4.49	4.85	5.22	5.88	6.50	7.04	7.67	8.34
9	2.14	2.59	3.04	3.43	3.82	4.22	4.61	5.00	5.38	6.06	6.70	7.25	7.89	8.56
9½	2.19	2.65	3.11	3.51	3.91	4.31	4.72	5.11	5.51	6.23	6.89	7.45	8.11	8.80
10	2.25	2.72	3.20	3.60	4.01	4.43	4.85	5.25	5.65	6.39	7.05	7.63	8.34	9.02
11	2.35	2.85	3.35	3.77	4.20	4.65	5.10	5.53	5.95	6.70	7.40	8.00	8.71	9.46
12	2.47	2.98	3.50	3.95	4.41	4.87	5.33	5.77	6.22	7.00	7.75	8.40	9.11	9.87
13	2.57	3.12	3.67	4.13	4.60	5.08	5.55	6.03	6.50	7.30	8.10	8.75	9.46	10.26
14	2.67	3.22	3.78	4.26	4.75	5.26	5.78	6.24	6.70	7.60	8.40	9.05	9.80	10.65
15	2.76	3.34	3.91	4.41	4.91	5.43	5.95	6.45	6.95	7.82	8.70	9.30	10.16	11.02
16	2.85	3.45	4.05	4.57	5.09	5.62	6.15	6.65	7.15	8.10	8.90	9.65	10.49	11.35
17	2.93	3.51	4.08	4.65	5.23	5.76	6.30	6.85	7.40	8.30	9.20	9.90	10.78	11.74
18	3.02	3.75	4.30	4.85	5.40	5.95	6.51	7.05	7.60	8.55	9.50	10.20	11.17	12.00

Figure 6. Example Waterman Rating Table for 24" C-10 Canal Gate.

RESULTS

Verification flow measurements and corresponding gate flow estimates based on the Waterman gate rating tables were plotted on an x-y plot (Figure 7). Figure 7 contains a sample size of 60 and includes all the flow measurement data for all gate sizes measured (18", 24", 30", 36", 42" and 48" diameters). Table 1 contains a tabular summary of the data from Figure 7. A least-squares linear regression was performed to determine the relationship between these two variables (Davis 2002). Forcing a y-intercept value of zero, the linear regression yielded Equation 5 after substituting orifice gate for 'y' and verification for 'x'. The R^2, or goodness of fit, for Equation 5 was 0.951. This means that roughly 95 percent of the variability in the orifice gate flow estimates is explained by the variability in verification flow measurements. It follows that, on average, the orifice gate estimates were 6 percent lower than the actual flow rate as defined by the verification measurements.

$$orifice\ flow\ estimate = 0.941 * verification\ flow\ measurement \qquad (5)$$

Gate Size (in)	Datetime	Full Stem (in.)	Dead Stem (in.)	Good Stem (in)	Head (ft)	Q Orifice (cfs)	Q Verification (cfs)	Residual (cfs)	% Difference
18	9/1/09 13:45	19 4/8	1 4/8	18	0.10	2.99	3.11	-0.13	-4%
18	9/1/09 14:15	4 4/8	1 2/8	3 2/8	1.88	3.81	3.82	-0.01	0%
18	6/2/09 12:40	6 6/8	2 6/8	4	2.66	5.50	4.68	0.83	18%
18	6/29/09 10:05	5 2/8	3 1/8	2 1/8	3.72	3.58	3.80	-0.22	-6%
24	6/29/09 9:10	20 6/8	2 4/8	18 2/8	1.18	15.69	15.80	-0.11	-1%
24	6/10/09 10:15	16 5/8	1	15 5/8	0.37	8.19	5.95	2.23	38%
24	6/29/09 7:00	3 5/8	1	2 5/8	1.26	3.41	4.26	-0.85	-20%
24	6/29/09 7:00	6 2/8	2 5/8	3 5/8	0.50	2.91	3.53	-0.62	-17%
24	5/18/09 8:08	7 1/8	4 4/8	2 5/8	5.18	6.91	6.76	0.15	2%
24	6/2/09 8:56	6 3/8	4 4/8	1 7/8	4.70	4.69	5.68	-0.99	-17%
24	6/10/09 8:40	6	4 4/8	1 4/8	6.23	4.41	5.41	-1.00	-19%
24	6/29/09 9:30	7 6/8	4 4/8	3 2/8	6.40	9.40	9.14	0.26	3%
24	8/14/09 9:30	7 7/8	4 4/8	3 3/8	1.15	4.13	4.23	-0.10	-2%
24	6/29/09 8:30	2 5/8	7/8	1 6/8	3.16	3.65	3.38	0.27	8%
24	6/29/09 7:00	2 6/8	1 4/8	1 2/8	1.08	1.53	1.98	-0.45	-23%
24	6/29/09 12:20	3 5/8	1 1/8	2 4/8	3.96	5.76	6.60	-0.83	-13%
24	8/4/09 10:42	3	1 1/8	1 7/8	4.23	4.51	4.83	-0.31	-6%
24	8/12/09 16:36	2 2/8	1 1/8	1 1/8	4.36	2.78	3.94	-1.16	-29%
24	6/2/09 12:40	6 4/8	1 6/8	4 6/8	1.80	7.10	6.18	0.92	15%
24	5/18/09 14:44	7	2 4/8	4 4/8	0.28	2.66	3.41	-0.74	-22%
24	5/18/09 14:44	4 4/8	3 7/8	5/8	3.16	1.33	3.41	-2.08	-61%
24	6/29/09 14:35	12 7/8	3 6/8	9 1/8	0.69	7.73	8.64	-0.92	-11%
24	8/26/09 10:00	7 2/8	3 6/8	3 4/8	1.62	5.07	5.26	-0.19	-4%
24	5/20/09 11:45	4 3/8	2 5/8	1 6/8	1.34	2.37	2.65	-0.27	-10%
24	7/16/09 11:58	4 4/8	2 5/8	1 7/8	1.44	2.63	2.13	0.50	23%
24	6/10/09 12:00	4 2/8	1 7/8	2 3/8	0.91	2.63	3.01	-0.38	-13%
24	8/26/09 14:45	12 4/8	4 5/8	7 7/8	0.71	6.95	7.75	-0.80	-10%
24	5/7/09 16:20	3 7/8	2	1 7/8	2.00	3.10	3.28	-0.18	-5%
24	6/2/09 14:05	4 5/8	1 6/8	2 7/8	1.42	3.94	4.79	-0.84	-18%
24	8/26/09 13:20	4 4/8	1 6/8	2 6/8	1.33	3.66	4.21	-0.55	-13%
24	6/29/09 13:45	5	7/8	4 1/8	0.73	3.97	4.00	-0.03	-1%
24	6/29/09 11:00	5 4/8	2 4/8	3	1.94	4.80	3.68	1.12	31%
24	7/21/09 13:23	8 3/8	3 2/8	5 1/8	0.51	4.05	4.17	-0.12	-3%
30	5/7/09 15:21	4 6/8	1	3 6/8	0.83	4.91	4.99	-0.08	-2%
30	5/18/09 15:33	17 1/8	2 3/8	14 6/8	1.43	21.26	22.32	-1.06	-5%
30	9/1/09 13:00	4 2/8	1	3 2/8	1.98	6.62	6.94	-0.32	-5%
30	5/7/09 17:10	10	6/8	9 2/8	0.45	8.24	8.27	-0.03	0%
30	8/4/09 13:35	6 3/8	6/8	5 5/8	0.15	3.06	2.78	0.28	10%
30	8/12/08 14:13	12	6/8	11 2/8	0.53	10.52	11.00	-0.48	-4%
30	8/12/08 14:42	9	6/8	8 2/8	0.57	8.35	9.28	-0.93	-10%
30	8/12/08 15:07	7	6/8	6 2/8	0.77	7.62	7.90	-0.28	-4%
30	8/12/08 15:32	5	6/8	4 2/8	0.88	5.70	5.75	-0.05	-1%
30	8/12/08 15:57	3	6/8	2 2/8	1.30	3.76	3.18	0.58	18%
30	5/20/09 12:45	3 5/8	2 3/8	1 2/8	2.01	2.63	2.13	0.50	23%
30	7/16/09 13:00	3 3/8	2 3/8	1	2.58	2.39	2.14	0.25	12%
30	7/16/09 14:22	9	4 2/8	4 6/8	0.59	5.18	4.30	0.88	20%
30	7/21/09 11:00	8 2/8	4 2/8	4	0.54	4.21	3.75	0.46	12%
30	5/14/09 15:32	5	2	3	1.65	5.60	4.72	0.87	19%
30	5/14/09 14:09	7	3 1/8	3 7/8	1.72	7.30	6.66	0.64	10%
30	6/2/09 10:55	8	4 1/8	3 7/8	0.95	5.42	5.34	0.09	2%
30	9/1/09 15:37	6 5/8	4 1/8	1 4/8	0.71	1.87	3.72	-1.85	-50%
30	6/2/09 10:55	2 6/8	7/8	1 7/8	0.67	2.26	2.48	-0.22	-9%
36	6/10/09 14:35	7 3/8	3	4 3/8	1.40	8.92	9.42	-0.51	-5%
36	8/4/09 10:08	7 3/8	3	4 3/8	1.37	8.82	8.94	-0.12	-1%
36	8/12/09 16:12	4 3/8	3	1 3/8	1.86	3.34	3.13	0.21	7%
36	6/2/09 9:50	3	1 1/8	1 7/8	1.88	4.55	3.33	1.23	37%
42	8/26/09 11:20	4 4/8	2 2/8	2 2/8	2.85	7.80	7.90	-0.10	-1%
48	5/7/09 8:20	1 4/8	1	4/8	0.65	0.97	2.61	-1.65	-63%
48	5/7/09 10:58	3 4/8	1	2 4/8	0.65	4.74	5.99	-1.25	-21%
48	5/14/09 11:19	10 4/8	1	9 4/8	0.89	19.51	23.64	-4.13	-17%

Table 1. Summary Data Table

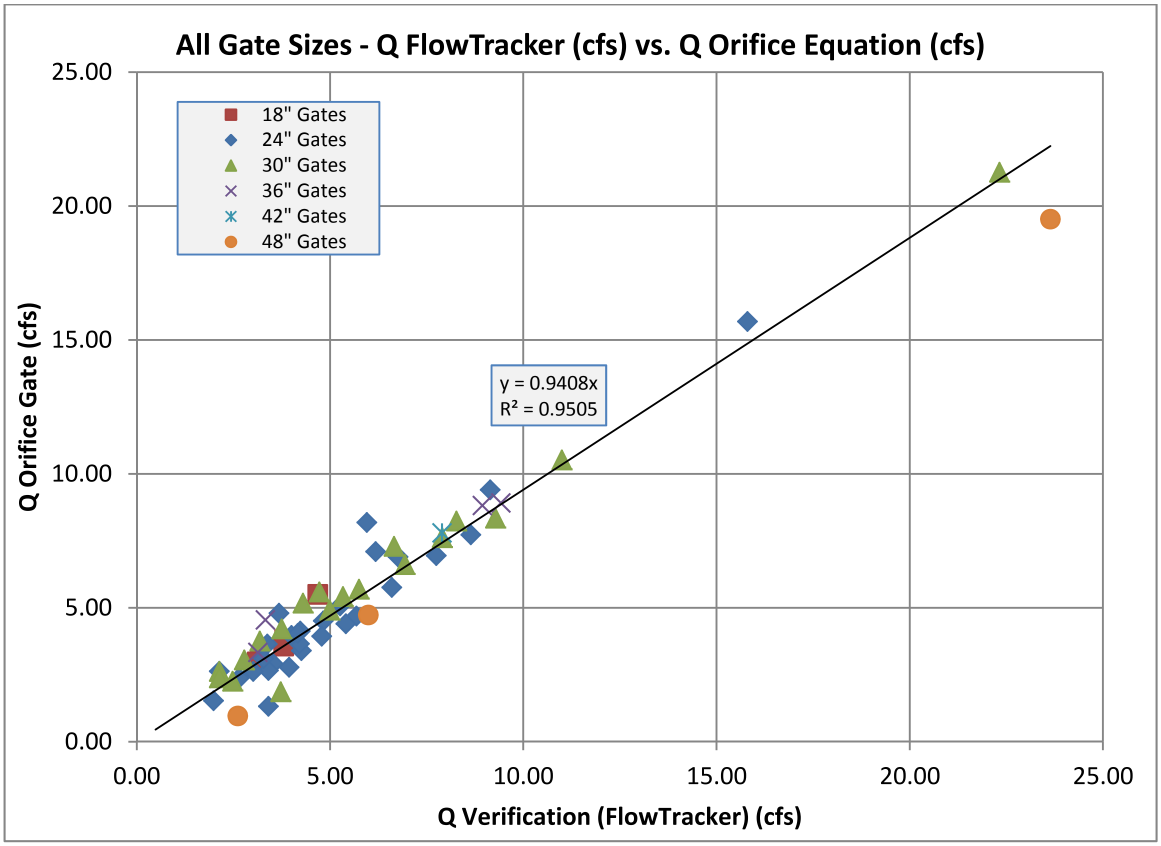

Figure 7. Estimated Q Orifice Gate vs. Measures Q Verification for Full Sample

Considering that most of the samples had flow rates of less than 12 cfs and that the 48" gates operating at low flow rates are extremely sensitive to error in the determinations of full-stem, dead-stem and good-stem, the analysis was repeated for a sample excluding all gates larger than 36" and any gate with a verification flow of 12 cfs or higher. Six gates were excluded leaving a sample of 54. A least-squares linear regression was performed to determine the relationship between the estimated and measured flows (Equation 6, Figure 8) (Davis 2002). The R^2 for Equation 6 was 0.888. This means that about 89 percent of the variability in estimated gate flow is explained by variability in the measured flow. This value is lower than the R^2 for Figure 7 and illustrates that, in addition to the error of the data points included in the regression, R^2 values are also sensitive to sample size delineations. It follows that, on average, for this sample the orifice gate flow estimates were 2.6 percent lower than the actual flow rates determined by the verification measurements.

$$orifice\ gate\ flow\ estimate = 0.974 * verification\ flow\ measurement \qquad (6)$$

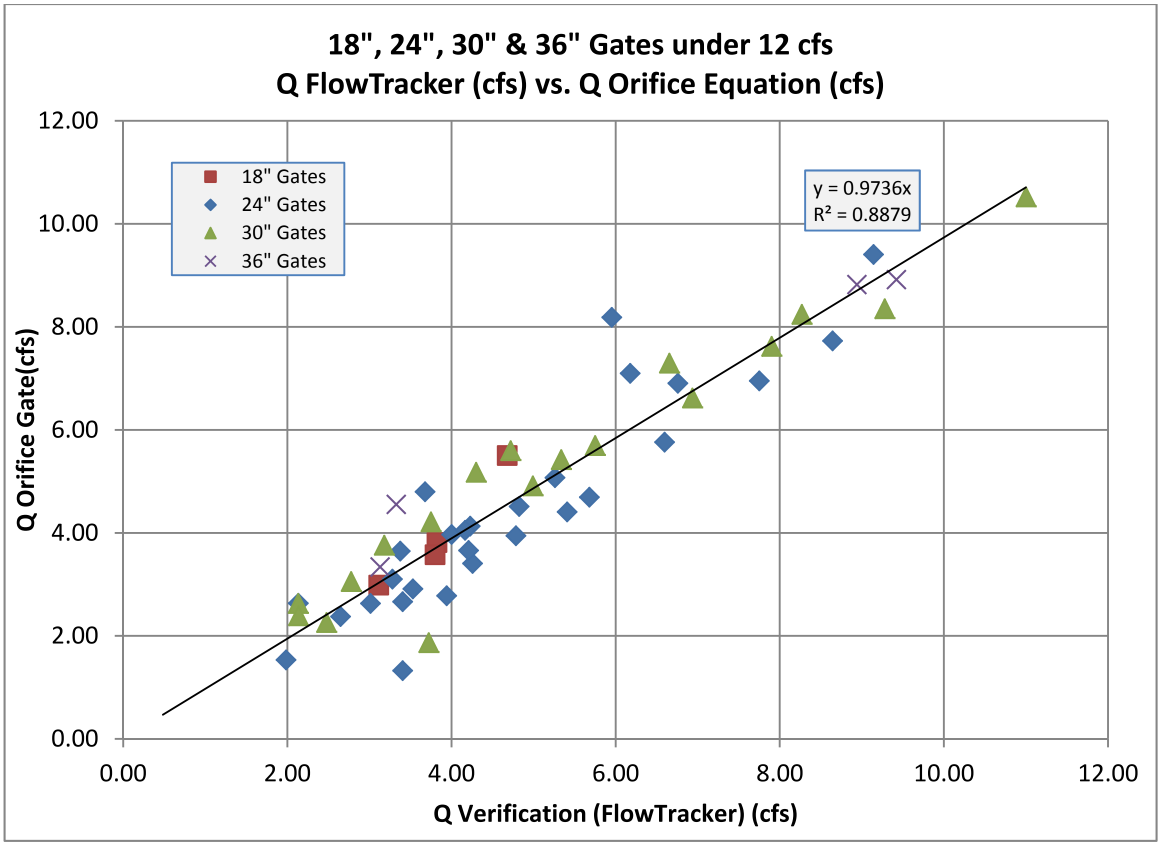

Figure 8. Estimated Q Orifice Gate vs. Measures Q Verification for Partial Sample

Additional analysis was performed on gates that had multiple verification measurements in an attempt to refine the characterization of the dead-stem values for these gates. The objective was to determine whether the verification flow data could be used to empirically calculate the dead-stem value. In other words, what would the dead-stem need to be in order for the orifice gate to be the same as the verification measurement? Figure 9 shows the percent difference in dead-stem for the sites with multiple verification measurements. If the percent difference in empirically derived dead-stem versus measured dead-stems remained consistent across multiple measurements, than it could be concluded that the dead-stem should be revised per this empirical approach. However, as illustrated in Figure 9, there was no consistent relationship in percent differences. This indicates that the empirically based dead-stem determination is unlikely to be a valid solution to the complications arising from accurately quantifying dead-stem values.

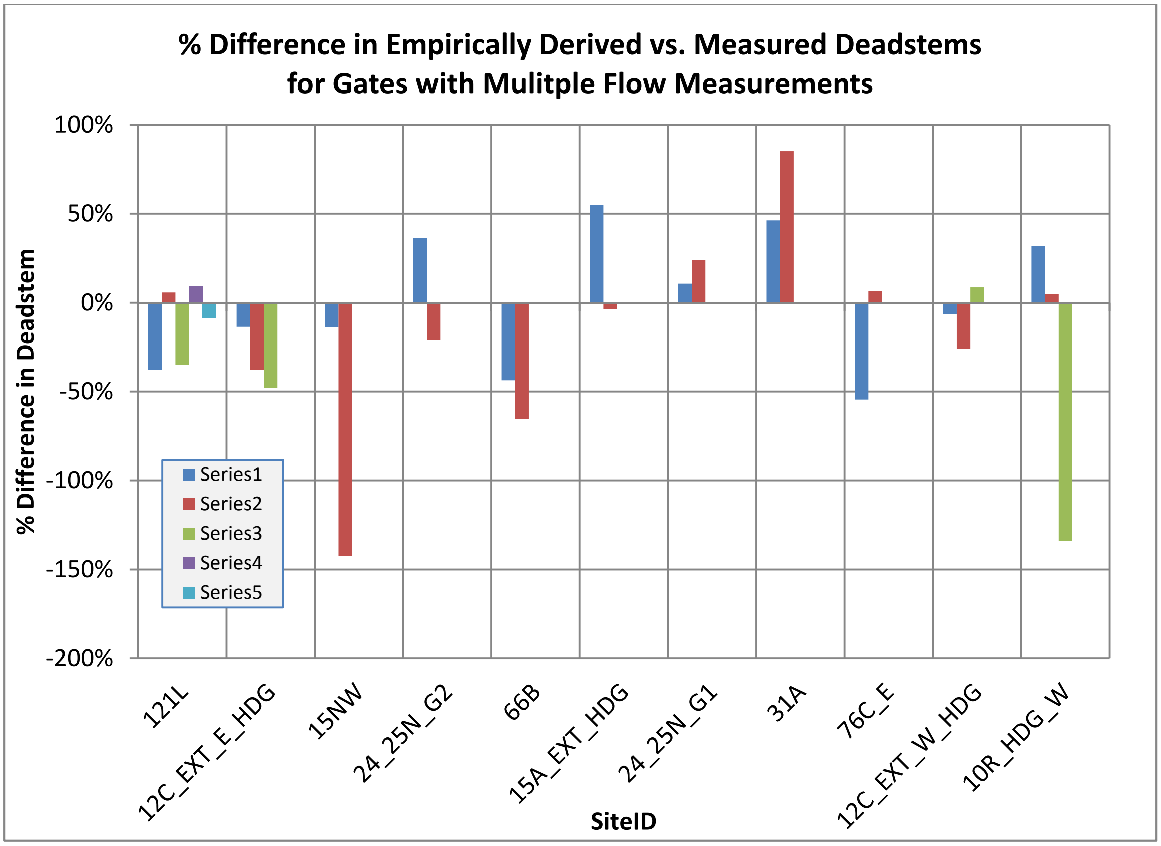

Figure 9.

IMPLICATIONS RELATIVE TO CALIFORNIA'S PENDING FARM DELIVERY GATE MEASUREMENT REGULATIONS

The Comprehensive Water Package passed by the California State legislature in November 2009 consists of four policy bills and an $11.14 billion water bond. One of the policy bills (SBx7-7) addresses both urban and agricultural water conservation and, with respect to agriculture, includes new requirements for agricultural water suppliers (over certain acreage thresholds) with respect to farm delivery measurement. RD 108 is over the specified threshold and is therefore subject to the new regulation. CWDR is responsible for developing and adopting regulations pursuant to SBx7-7, a process that was formally launched in July 2010 with respect to the agricultural aspects of the law and is ongoing as of this writing.

SBx7-7 requires that on or before July 31, 2012, agricultural water suppliers subject to the law shall measure the volume of water delivered to customers with sufficient accuracy to:

(1) Enable reporting of aggregated farm-gate delivery data to the state and

(2) Adopt a pricing structure for water customers based at least in part on the quantity of water delivered.

The presumed purpose of the requirement to report aggregated farm deliveries is to provide information that the state and others can use to better understand agricultural water use in California. New requirements for volumetric pricing, again presumably, are to induce on-farm conservation through water pricing.

During the latter half of 2010 and first half of 2011, CDWR developed its draft regulation with the input and involvement of an Agricultural Stakeholder Committee comprised primarily of staff from agricultural water supplier staff and environmental advocacy organizations, plus some academics and consultants.

CDWR's emergency regulation adopted on July 5, 2011 requires that existing farm delivery gates like those in RD 108 have a measurement accuracy of ±12% by volume, meaning that the measured volume of water delivered at each farm delivery point must be no greater than 12% more, or 12% less than the actual volume. The regulation requires that accuracy certification be performed by either: (1) field testing of a random and statistically representative sample of existing gates, or (2) field inspections and analysis of every existing delivery gate, with the testing or inspections documented by a registered engineer.

Although the original intent of RD 108's measurement verification program was not related to the pending regulation, the data provides insight into the likely implication of the regulation if adopted as drafted. It is noted that the regulation applies to the *volume* of water delivery whereas the verification measurements are for *flow rate*. For purposes here, it is assumed that flow rate accuracy as determined through RD 108's verification measurements is representative of volume accuracy. The implied assumption is that no additional error would occur in integrating observed farm delivery gate flow rates over time to estimate delivered water volumes.

The relative (%) error of each data pair was calculated as the difference between the measured and actual flow values divided by the measured value (Equation 7), where the flows estimated using the rating table are regarded as the measured flows and the flows measured using the FlowTracker are regarded as the actual flows. This definition of accuracy is consistent with the draft regulation.

$$\%\,error = (measured\ flow\ rate - actual\ flow\ rate) /\ actual\ flow\ rate \qquad (7)$$

The distribution of relative error among the full population of 60 gate measurements is illustrated in Figure 10. Just 33 gates, or 55% of the sample, would satisfy the ±12% accuracy standard in the CDWR emergency regulation, with the remaining 45% of the gates falling outside the standard. The emergency regulation states that if more than 25% of a sample of existing measuring device falls outside of the ±12% accuracy standard, a plan to test an additional 10% of the population[4] must be developed and submitted as part of the District's Agricultural Water Management Plan. Thus, if this sample of measurements was used for compliance with the new regulation, the District would be

[4] The regulation states that the 10% of the population selected for the second round of field-testing should be no less than 5 and no greater than 100.

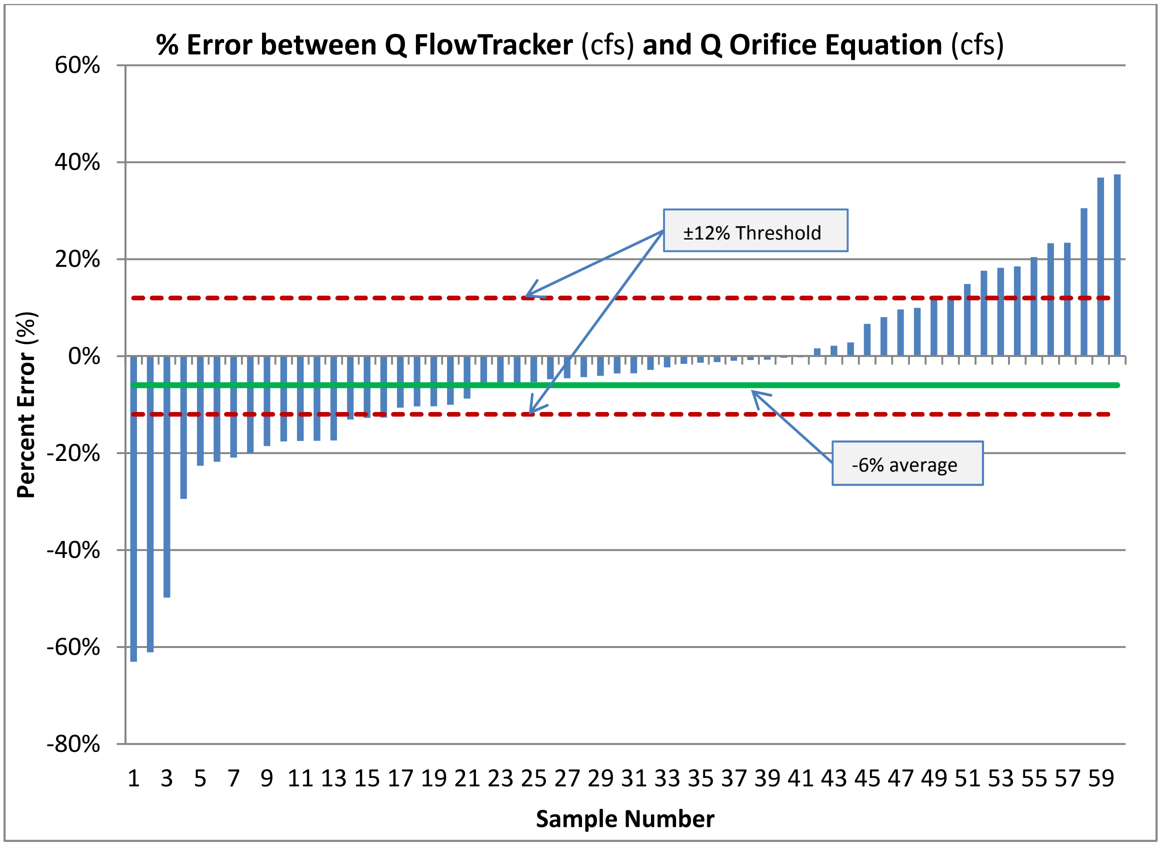

Figure 10. Percent Error between Measured Flows and Flows Estimated with the Gate Rating Table

required to conduct additional testing because more than 25% of the sample falls outside the standard. According to the regulation, the additional testing and corrective actions need to be completed within a three year period of the initial field-testing[5]. Options for bringing gates into compliance include: correcting non-standard hydraulic conditions where they can be identified; developing custom, gate-specific rating tables; reducing slack and hysteresis in gate stem measurements; and installation of improved measurement devices. All of these are expensive options.

It is interesting to note that the distribution of error is somewhat random, meaning that the positive and negative errors tend to cancel out. As noted above, the average error among this sample of gate measurements was just -6%; however, the draft regulation does not have a standard that applies to the average error for a population of gates, which, ironically, is important for purposes of aggregate reporting. The assumption implicit to the draft regulation is that, if a population of measure devices complies with the ±12% standard, the average error for all gates will probably be acceptable.

[5] The emergency regulation is not clear with regard to the implication of the initial or second round of field-testing or inspection verification approaches. In either case, if accuracy deficiencies are discovered, it is not clear whether just the outliers within the sample would need to be corrected, or whether all non-compliant gates must be included in the second round of field-testing.

Review of the RD 108 test data relative to the draft accuracy regulation reveals important philosophical questions, the main one being the role of government in regulating the relationship between agricultural water suppliers and their customers, in this case the accuracy of water delivery measurement. In this context, it is worth noting that water suppliers are in most cases are non-profit local government agencies formed and governed by the landowners they serve. Given this dynamic, is it state government's role to develop and enforce regulations to address an issue that would inevitably be dealt with locally between landowners and their district to mutual satisfaction?

Ironically, in the case of RD 108, the accuracy of existing measurement devices appears to be sufficient for purposes of reporting aggregate farm deliveries to the state, one of the expressed purposes of SBx7-7, but, again, the regulation is silent in this regard. Instead, the draft regulation focuses on individual device accuracy and proposes numeric standards that could have costly implication to RD 108 operations with questionable water management benefits.

CONCLUSION

Sixty orifice gate flow measurements were analyzed for this investigation. The measurement error at individual gates ranged from -63 to 38 percent relative to independent flow measurements made with a SonTek FlowTracker Acoustic Doppler Velocimeter (ADV) using the open channel, mid-section current metering methodology. The error distribution was nearly random, such that the positive and negative errors tended to cancel out. On average, orifice gate measurements were about 6 percent lower than the independent flow measurement.

Just 33 gates, or 55% of the sample, would satisfy the ±12% measurement accuracy standard in the CDWR emergency regulation adopted July 5, 2011, with the remaining 45% of the gates falling outside the standard. Therefore, in order to comply with the regulation, RD 108 could be faced with the prospect of having to perform a second round of field-testing and to implement corrective actions within a three year period of the initial field-testing, even though the average error among gates is just -6%. Any expenditures to improve gate measurement accuracy will provide questionable benefits and delay planned investments in other water management facilities and programs.

ACKNOWLEDGEMENTS

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VELOCITY DISTRIBUTION AND FLOW MODELLING IN SMALL IRRIGATION CANALS

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Craig Huhta[2]
John Sloat[3]

ABSTRACT

Accurate metering of agricultural water is becoming increasingly important world wide. Surprisingly, the dynamics of water in small irrigation canals are not well understood and this limits the accuracy of flow measurements in these channels. To help improve the accuracy of flow data, we performed detailed measurements of the velocity distribution for a variety of flow conditions in a several small irrigation canals. The data collected represent one of the most detailed velocity distribution studies ever undertaken in field conditions for this type of channel. The data were compared with different theoretical velocity distribution models. The results of these comparisons will be presented, along with conclusions about which models are most appropriate for predicting the velocity distribution in these channels. The goal of this project is to support the development of new flow sensors for small irrigation canals that provide improved measurement accuracy.

INTRODUCTION

In much of the world, the majority of agricultural water is delivered through small open irrigation canals. Water measurement is extremely important – the water resource cannot be managed well unless it is measured and controlled throughout the complete web of water delivery and recirculation systems. Based on discussions with water managers and industry leaders, we found a significant gap in available instrumentation for channels with depths ranging from 0.05 to 1.5 m, and widths from 0.3 to 5.0 m. There are tens of thousands of these channels around the world; in one part of the western United States alone, one survey identified 35,000 such sites (ITRC 1996). Other regions of the world with extensive networks of these canals include Australia, China, India, and southern Europe.

Existing flow measurement technology is often based on water level using some type of control structure (a rated gate, weir or flume), or may use velocity plus water level measurement via electro-magnetic (EM) or mechanical means. Control structures typically require a loss of head, which for many canal systems is not feasible. Existing water velocity instruments often rely on a measurement at a single point within the channel that may not be representative of the total cross section. As complex flow conditions exist even in these small channels, detailed measurements of the velocity

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distribution, in addition to water level, will yield a more robust flow measurement across a wider range of channel conditions.

To accurately measure flow, it is necessary to understand the flow conditions that exist within these small channels. We performed detailed measurements of the velocity distribution in several different channels to help provide this understanding. These measurements were then compared to different velocity distribution models to see which models most accurately reproduce the flow conditions seen at these sites. The results of these comparisons are presented here. From these comparisons, we conclude which models most accurately represented the flow conditions that we observed.

VELOCITY DISTRIBUTION MEASUREMENTS

We were unable to locate any existing detailed velocity distribution data for these channel types, so we performed measurements at a number of sites in the western United States. The measurements were performed in cooperation between SonTek/YSI and the Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo, California.

Data Collection Procedure

All velocity measurements were made with a SonTek/YSI FlowTracker®, a high precision single point velocity sensor. A preliminary site was sampled with a larger measurement density and duration than would be practical for measurements at multiple sites. Results from this site were used to develop field data collection procedures. Data for each field site includes a detailed survey of channel geometry and velocity measurements at 10 or more locations across the width of the channel and 1-6 different depths for each location. Each velocity measurement lasted 40 seconds.

Sites were generally selected at a transition point within a channel; this might be a control gate, a bend, or a change in channel geometry. Measurement cross sections were then located at different distances moving downstream from the transition point, providing data to examine the distance required to reach a well defined flow distribution. Depending upon the channel geometry and other logistical details, a single site required about 4 hours for a team of two people to complete the required field work. Measurements were coordinated with local irrigation managers to ensure steady flow conditions during the period of each measurement.

A temporary walkway was placed across the channel so that measurements could be made without requiring the operator to enter the water, which would significantly alter the velocity distribution. When practical, the same site was sampled at different flow conditions; in practice, this was only possible at a limited number of sites since flow conditions were determined by the water requirements at any given time and could not normally be adjusted to suit our measurement needs.

Figure 1. Example Measurement Site with Walkways for Two Cross Sections

Example Velocity Distribution Data

Figure 2 shows an example of velocity distribution data where a total of 57 velocity measurements were made at multiple points along 12 different verticals; the location of each measurement is shown with an asterisk (*). The velocity distribution in the canal is shown using a contour plot, with different colours representing different velocities as shown in the scale to the right of the figure. The site in Figure 2 represents one of the more uniform and predictable velocity distributions seen in our data. The velocities are skewed slightly towards the right side of the channel, but in general it shows decreasing velocities that would be expected as you approach the bottom and sides of the channel. It was interesting to discover the degree of variation seen in these measurements, even in seemingly perfect measurement sites. Figure 3 shows the distribution at a cross section in the middle of a long, straight, uniform, concrete lined canal that had been cleaned immediately prior to these measurements. The nearest change in the canal was more than 100 m away from this site. This illustrates that even at seemingly perfect measurement sites, detailed measurements of the velocity distribution are needed for an accurate flow calculation. For sites with large amounts of sediment on the bottom or other irregularities, the velocity distribution was often highly unpredictable.

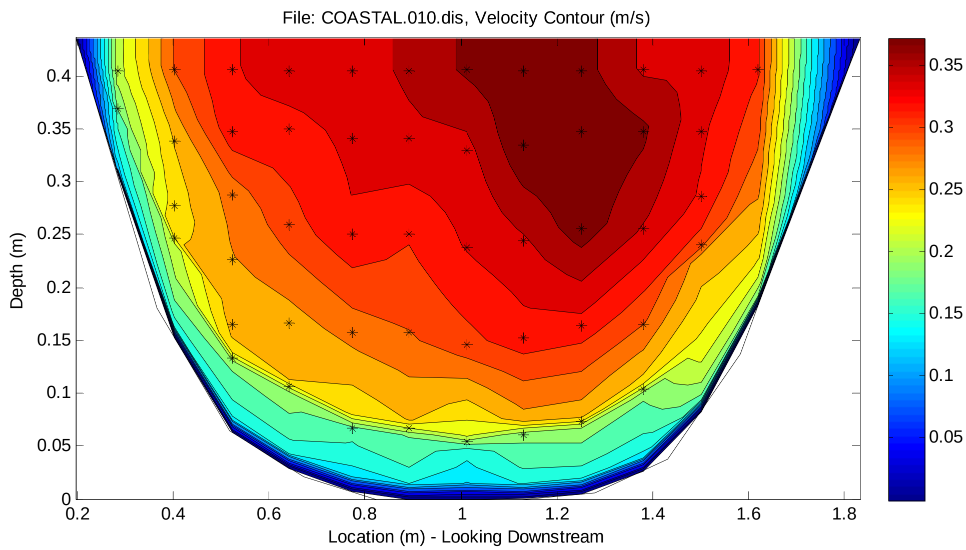

Figure 2. Example Velocity Data

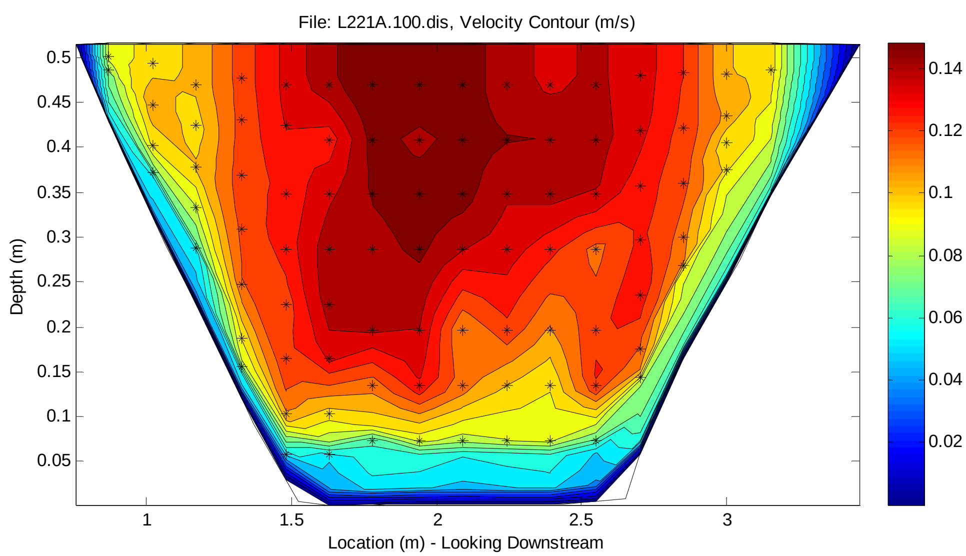

Figure 3. Example of Irregular Velocity Distribution

FLOW MODEL COMPARISON

The objective of the flow modelling in this project was to assist in the development of a new sensor to measure flow in small canals. The new sensor will use pulsed acoustic Doppler profiling technology to measure the velocity in some portion of the canal. Acoustic Doppler systems can be split into two categories: continuous wave and pulsed. As the name suggests, continuous wave systems transmit and receive continuously, measuring the velocity of water along the entire beam path at the same time. It is not possible to distinguish the exact location of the measurement nor is it possible to know the spatial distribution of the velocity measurement along the beam. Pulsed Doppler systems transmit a short acoustic pulse and measure the response versus time, thereby measuring a profile of velocity along the path of the acoustic beam. A system designed for small canals can achieve a resolution of the spatial distribution of velocity to the order of a few centimetres. A system with multiple beams oriented in different directions can measure the velocity along each beam, thus giving the velocity distribution in different portions of the canal.

The goal of our flow modelling is to determine the number and orientation of acoustic beams needed so that the total flow in the channel can be extrapolated from the data measured by those beams. In particular, we wanted to determine the accuracy of the flow estimate for a given environment and beam configuration. Several models were evaluated and compared to data collected in the field. Given space limitations, only a brief description of each model is given in the sections that follow.

Power Law

The power law is one of the most widely used models for open channel flow. Eq. (1) below is a common expression of the power law velocity distribution (Chen, 1991).

$$\frac{u}{u^*} = a\left(\frac{y}{y'}\right)^m \qquad (1)$$

where *u is* velocity at any point; u^* is boundary shear velocity; a is a constant; y is the distance to the boundary (for velocity point u); y' is the characteristic length for zero velocity isovel; and m is a constant, typically in the range 1/2 to 1/10 (1/6 is a common value).

We are using the power law to fit and extrapolate from measured velocity data, so we do not attempt to derive values of y' and u^* from boundary conditions. Thus we can incorporate these into the constant a_1 giving the simpler expression of Eq. (2).

$$u = a_1 y^m \qquad (2)$$

The power law was developed for the ideal cases of a wide channel of constant depth or an axisymmetric conduit; boundary distance is the vertical height above the bottom for the former and the radial distance from the boundary for the latter. For a typical irrigation canal, this value cannot be accurately used as we approach the walls of the channel. We have instead used the shortest normal (perpendicular) distance to the boundary for y, which is consistent with boundary-layer theory.

The exponent m is a key parameter in applying the power law, as it is the primary driver for the shape of the velocity distribution. The value of m is influenced by a number of factors, perhaps the two most important being boundary roughness and turbulence. We have treated these as constant for any given cross section in a given flow conditions; thus a cross section will have a single m value to represent the entire cross section, though m

might vary with time.

When applying the power law to velocity data, we have tried a number of variations to see which would yield the best results.

- Computing the optimum value of *m* based on all velocity data in the cross section.
- Computing the optimum value of *m* based only on the vertical velocity profile in the centre of the channel. This would be comparable to having an instrument that measures the vertical profile of velocity in the middle of the channel.
- Computing a single value of the constant *a* for the entire cross section.
- Allowing *the value of a to vary across the width of the channel. This would be comparable to having an instrument that measures the horizontal variation of velocity across the channel.*

Another common flow theory is the logarithmic law (Chen, 1991). Both log law and power law are members of a family of functions that can simultaneously satisfy the partial differential equations for the 'inner law' and the 'outer law' in fluid mechanics. From a fluid mechanics and mathematical perspective, the two theories are equivalent; we selected the power law because it is easier to apply.

Chiu's Maximum Entropy Method

In recent years, a probabilistic approach to modelling open channel flow has gained increasing acceptance; it is sometimes called the maximum entropy method (Chiu, 1989, Chiu & Hsu 2006). This method predicts a constant relationship between the mean and maximum velocity at any given cross section, and thus provides a theoretical underpinning for the widely used index velocity method (Morlock et al, 2001). The method is very attractive as it simplifies the monitoring of discharge by reducing the number of velocity measurements required.

The maximum entropy method can also be used to calculate the velocity distribution in a channel. Predicting velocity distribution in a channel requires coupling the entropy-based equation for velocity (Eq. 3) with an equation describing the shape of isovel curves based on the geometry (Eq. 4).

$$u = \frac{u_{max}}{M} ln\left[1 + (e^M - 1)\frac{\xi}{\xi_{Max}}\right] \tag{3}$$

$$\xi = Y(1 - Z)^{\beta_i} \exp(\beta_i Z - Y + 1) \tag{4}$$

where $u_{Max}$is the maximum velocity in the cross section; *M* defines the ratio of mean to maximum velocity $\left(\frac{\bar{u}}{u_{max}} = \frac{e^M}{e^M - 1} - \frac{1}{M}\right)$ (typically in the range 1 to 10); ξ is an index variable representing velocity on an isovel; *Y* and *Z* are dimensionless coordinates in vertical and lateral direction, respectively; β_i are coefficients to define horizontal distribution (typically in the range 1 to 10), *i*=1 for left of Y_{Axis} and *i*=2 for right of Y_{Axis}; Y_{Axis} is the location of the maximum velocity across the width of the channel. Hence, to define the velocity distribution, we have four independent parameters (*M*, Y_{Axis}, β_1, and

β_2).

With detailed velocity measurements throughout the cross section, we can reasonably assume that we have measured the maximum velocity and so we can know the location Y_{Axis} directly. The parameter M was determined two ways.

- M can be calculated from the ratio of the mean to maximum velocity in the channel, which can be directly calculated from our velocity measurements.
- The vertical velocity profile at the Y_{Axis} can be predicted based on the value of M and the measured maximum velocity. Thus we can determine a value of M by performing a best fit of the vertical velocity profile as measured at the Y_{Axis}.

The remaining parameters, β_1 and β_2, were fit to the measured velocity data using a least-squares approach once we determined values for Y_{Axis} and M.

Maghrebi and Rahimpour's Approach

One significant limitation of many flow models (including the power law and logarithmic law) is that they are developed for an ideal boundary condition of a wide, shallow stream with a flat bottom. This is a problem in narrower channels where the exact bottom contour and wall effects must be taken into account. An interesting model has been recently proposed that provides a method for accounting for bottom and wall effects by integrating any other model of open channel flow to account for an arbitrarily shaped channel boundary (Maghrebi & Rahimpour, 2005, Maghrebi & Rahimpour, 2006). The basic idea of this model is that every part of the boundary has an effect on the velocity at each point within the boundary. So given a model that describes the effect of the boundary on velocity, if you integrate this model over the true boundary shape you can describe the flow pattern in any arbitrarily shaped boundary.

Although we found this concept extremely intriguing, we encountered a problem that prevented its practical use. Most models were developed not for the influence of a single point on the boundary but rather for the influence of an assumed boundary shape. The simplest way to illustrate this is to look at the basic power law relation shown in Eq. (2). This equation says that the velocity at some distance y from the boundary is proportional to that distance raised to the power m. However, if we integrate Eq. (2) over an arbitrary boundary shape, the exponent changes, thereby dramatically changing the basic shape of the velocity distribution. For example, for the ideal case of the wide flat channel for which the power law was developed, the exponent in Eq. 2 approaches unity, resulting in a linear velocity profile. We attempted various modifications to this theory to avoid this problem, but were unable to find an effective method. It is our hope that additional work on this concept can overcome these problems, as seems to hold promise as an effective tool to predict velocity in any arbitrarily shaped channel.

Evaluation Criteria

We determined a best fit of each theoretical distribution for a particular channel, using some or all of the velocity data collected (depending on the particular theory and

implementation). Using these best-fit parameters, we then calculated the predicted velocity at the location of each of our velocity measurements in the cross section. We then calculated the root mean square (RMS) of the difference between the predicted and measured velocity values. The RMS error was converted to a percentage dividing by the mean channel velocity for that cross section; mean channel velocity is discharge divided by cross sectional area.
As a second evaluation criterion, we used the same routine to estimate velocity data at each measured location. We then compared the total channel discharge using the measured velocity data, and compared this to discharge calculated using the theoretically predicted velocity data. This "discharge error" is particularly relevant for our study as our final goal is to assist in the development of a new sensor for monitoring flow in this type of channel.

COMPARISON RESULTS

Fifteen cross sectional measurements were selected for detailed analysis. These all have a reasonably well developed velocity distribution, and represent a good variety of small irrigation canals. Table 1 below provides basic details for each cross section. If the same location was measured at different flow conditions, the rows from that location have been highlighted in the same colour.

Table 1. Description of Measurement Cross Sections

Site	Lining	Q (m^3/s)	Depth (m)	Mean Vel (m/s)	Comments
1	Concrete	0.22	0.41	0.36	Clean channel
2	Natural	0.62	0.41	0.47	On gradual bend, stable bed
3	Concrete	0.16	0.44	0.30	Clean channel
4a	Concrete	0.11	0.61	0.09	Heavy bed sediment, higher flow rate
4b	Concrete	0.12	0.32	0.24	Clean channel, higher flow rate
4c	Concrete	0.03	0.40	0.05	Heavy bed sediment, lower flow rate
5a	Concrete	0.12	0.71	0.07	Heavy bed sediment, higher flow rate
5b	Concrete	0.11	0.52	0.12	Clean channel, higher flow rate
5c	Concrete	0.03	0.48	0.03	Heavy bed sediment, lower flow rate
6a	Concrete	0.11	0.69	0.12	Heavy bed sediment
6b	Concrete	0.12	0.69	0.17	Clean channel
7	Natural	0.05	0.30	0.09	Stable bed
8	Concrete	0.55	0.74	0.39	Clean channel
9	Concrete	0.40	0.65	0.34	Clean channel
10	Concrete	0.48	0.69	0.56	Clean channel

The following models were evaluated for how well they matched measured data.

A. Power Law #1: *m* value from entire cross section, single *a* value for entire cross section.
B. Power Law #2: *m* value from entire cross section, vary *a* across width of channel.
C. Power Law #3: *m* value from centre of channel, single *a* value for entire cross section.
D. Power Law #4: *m* value from centre of channel, vary *a* across width of channel.
E. Maximum Entropy #1: Y_{Axis} based on location of maximum velocity, M from mean and maximum velocity, best fit β_1 and β_2 parameters.
F. Maximum Entropy #2: Y_{Axis} based on location of maximum velocity, M by best fitting the vertical velocity profile at the Y_{Axis}, best fit β_1 and β_2 parameters.

Table 2 shows the RMS velocity error for all models at each cross section, as a percentage of the mean velocity at that cross section. Table 3 shows the percent error in total discharge for all models at each cross section. The error is determined by comparing discharge calculated using the measured velocity points to discharge calculated using the predicted values, as a percentage of discharge from measured velocity data.

Analysis of table 2 indicates that the models all performed equally when considering the RMS error of the individual velocity points. While some measurements showed relatively small errors (< 10%) among all methods, median RMS errors were around 20% with some measurements showing RMS errors in the velocity larger than 50%. All of the velocity distribution models imply a well-behaved relation (e.g., continuous function and gradient, usually monotonic); in reality velocity distributions often are not mathematically well behaved (e.g., Fg. 3), resulting in large errors between the mathematical function and the measured velocities. It is worth noting that the measurements with the largest RMS error (4a and 4c) were located at the same cross section as one of the measurements with the lowest RMS error (4b). However, measurement 4b was after the channel was cleaned. Furthermore, all of the measurements with RMS errors less than 10% are for clean concrete channels. This implies that prediction of the velocity distribution in the cross section is affected by the condition of the channel.

Table 2. RMS Percent Error of Velocity Data

Site	Model A	Model B	Model C	Model D	Model E	Model F	Median
1	6.0%	7.0%	6.2%	6.9%	9.7%	9.6%	7.0%
2	24.7%	22.6%	32.3%	18.1%	15.9%	17.6%	20.4%
3	6.1%	5.0%	6.5%	4.9%	10.9%	10.7%	6.3%
4a	38.7%	33.1%	51.3%	33.8%	49.6%	48.8%	43.8%
4b	6.0%	6.2%	6.3%	6.2%	14.2%	12.9%	6.3%
4c	50.2%	62.2%	55.3%	60.3%	94.6%	93.6%	61.3%
5a	19.1%	19.7%	26.3%	26.5%	29.4%	29.4%	26.4%
5b	9.0%	10.2%	9.3%	10.4%	14.2%	14.2%	10.3%
5c	23.4%	33.6%	29.9%	32.3%	35.4%	35.4%	33.0%
6a	20.9%	14.2%	21.8%	14.9%	21.0%	21.6%	21.0%
6b	16.7%	14.5%	20.5%	14.4%	16.7%	15.1%	15.9%
7	17.9%	18.3%	19.1%	18.3%	14.6%	14.9%	18.1%
8	19.7%	14.3%	24.7%	17.8%	17.5%	16.9%	17.7%
9	17.5%	14.8%	20.2%	14.5%	22.9%	22.6%	18.9%
10	8.4%	8.9%	9.4%	8.2%	7.5%	8.0%	8.3%
Mean	**19.0%**	**19.0%**	**22.6%**	**19.2%**	**24.9%**	**24.8%**	
Median	**17.9%**	**14.5%**	**20.5%**	**14.9%**	**16.7 %**	**16.9%**	

Table 3. Percent Error in Discharge Calculation

Site	Model A	Model B	Model C	Model D	Model E	Model F	Median
1	-0.4%	2.0%	-0.1%	1.5%	5.0%	4.6%	1.8%
2	-3.2%	9.3%	15.1%	4.0%	3.8%	5.5%	4.8%
3	-0.4%	-1.4%	-1.6%	-1.3%	8.0%	7.3%	-0.9%
4a	9.7%	-0.7%	-22.5%	1.7%	27.4%	28.0%	5.7%
4b	0.2%	-0.4%	1.6%	-0.5%	8.8%	7.7%	0.9%
4c	6.2%	-23.8%	-16.5%	-23.4%	7.9%	29.5%	-5.2%
5a	3.1%	9.5%	-12.1%	16.6%	18.6%	20.6%	13.1%
5b	3.0%	3.3%	2.2%	3.5%	7.0%	7.4%	3.4%
5c	-1.3%	-16.1%	-11.3%	-14.7%	23.9%	19.9%	-6.3%
6a	3.0%	5.0%	2.9%	6.4%	11.0%	13.7%	5.7%
6b	-1.3%	3.6%	7.7%	1.8%	6.2%	4.7%	4.2%
7	-3.9%	-0.8%	2.4%	-1.6%	0.6%	1.0%	-0.1%
8	0.7%	1.1%	-11.1%	9.3%	8.3%	6.7%	3.9%
9	-2.9%	-5.2%	-11.9%	-4.1%	11.8%	11.5%	-3.5%
10	1.4%	-1.9%	-1.7%	-0.7%	5.6%	4.2%	0.4%
Mean	1.0%	-1.1%	-3.8%	-0.1%	10.3%	11.5%	1.9%
Median	0.2%	-0.4%	-1.6%	1.5%	8.0%	7.3%	1.8%
Mean(Abs)	2.6%	5.6%	8.1%	6.1%	10.3%	11.5%	7.1%
Median(Abs)	2.9%	3.3%	7.7%	3.5%	8.0%	7.3%	4.8%

Table 3 indicates that despite the large errors in predicting the velocity distribution, the models based on the power law provided a relatively good prediction of the discharge past the cross section, with the median of the errors on the order of 3% and the number of overestimates and underestimates nearly equal. Model B, which has more adjustable coefficients than Model A, results in larger errors than Model A. This is a result of the increased influence of profiles that do not behave as the models predict when modelling section-by-section. In contrast to the power-law models, the models based on Chiu's maximum entropy method consistently overestimated the discharge past the cross section, with all discharge predictions overestimating the measured value. Chiu's method uses the parameter M to assign velocities to the isovels from (Eq. 4). While results from laboratory flume studies and selected measurements on larger streams showed good results, our results indicated that neither determining M from the ratio of the mean and maximum velocities nor determining M from the velocity profile at the Y_{Axis} provided a good estimate of the velocity distribution for these small channels. It is interesting to note that the two different methods of calculating M often yielded significantly different values for this key parameter. Determining M from the velocity profile along the Y_{Axis} often provided a poorer estimate of the flow in the channel than determining M from the mean and maximum velocities.

CONCLUSIONS

Several conceptual models of 2-D velocity distribution for open channels were examined to see which models most accurately reproduce the flow conditions seen at these sites. The model of Maghrebi & Rahimpour, while providing an intriguing approach to account for arbitrary-shaped cross sections, does not maintain the basic premise of velocity distributions even for an ideal case of a flat plane. Hence this was not examined further. Comparison of models based on the power law and Chiu's maximum entropy approach indicated that both approaches perform similarly in terms of estimating the velocity distribution with a RMS error on the order of 20%. However, examination of the discharges determined based on these models indicates that the models based on the power law provide an unbiased discharge prediction with errors on the order of 3% while models based on the entropy approach consistently overpredicted the discharge on the order of 8%.

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THE SCENIC WATERWAY ACT:
A TYPE OF INSTREAM FLOW REQUIREMENT —
CASE STUDY OF OREGON'S GRAND RONDE RIVER BASIN

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ABSTRACT

In the wake of ever increasing environmental rules and regulations, the effects can be far reaching with unexpected consequences. In the Grande Ronde Basin and other parts of Oregon, the Oregon State Scenic Waterway Act ("SWA") affects the ability to successfully secure new ground water appropriations.

The SWA (following the federal Wild and Scenic Rivers Act) was enacted by Oregon in 1970. Today most scenic waterways are established by statute; however the designations can also be made by the Governor. The SWA declares that the highest and best uses of waters within the scenic waterways are recreation, fish and wildlife uses. The extent of the protected flows are generally established by word of mouth from the local, self-interested fisherman and rafters along these designated waterways—not scientists or sophisticated computer modeling! The areas protected under the SWA itself are those related adjacent lands which include ¼ mile to 1 mile from the bank along the scenic stretch.

The Oregon courts decided that the statutory protection was not enough, and with judicial activism engaged, Oregon case law established in the late 1980's that the reach of the SWA would extend to any new water diversions that are *within or above* a scenic waterway. This "within or above" language is now interpreted to mean that any new well drilled 25 miles above the designated scenic waterway within a hydrologically connected aquifer will be evaluated under the SWA!

In the Grande Ronde, the cumulative impact threshold was reached against the SWA designated stretch as determined by Oregon Water Resources Department ("OWRD") in January 2006. With an OWRD finding that the shallow alluvial aquifer in the Grande Ronde basin was hydraulically connected to the Grande Ronde River, all new ground water applications that attempt to withdraw water from the alluvial "connected" aquifer are being denied during the OWRD's evaluation process.

This topic will consider and discuss how the SWA affects ground water through hydraulic connection, and thus affects new and/or existing water appropriations.

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INTRODUCTION

The passage of the Wild and Scenic Rivers Act by the United States Congress in 1968, along with analogous state laws enacted shortly afterwards, dramatically increased the protection that rivers and river segments designated under the Act, receive across the nation. One of the original results of the increase in protections included greater restrictions on surface water use in designated river areas. In some states the restrictions on water use have been extended in the subsequent decades to include ground water resulting in the area of protection being greatly expanded. In many river basins where only the lower reaches of the basin are designated, the restrictions on water use created by scenic waterway laws have led to denial of water use applications, both surface and ground water, for the entire river basin. Oregon's Grande Ronde River Basin provides an excellent example of a scenic waterway act combined with judicial interpretation and expansion that has resulted in the complete denial of all new water right applications within an entire river basin without the benefit of any statute or rule-making..

THE WILD AND SCENIC RIVERS ACT OF 1968

With the passage of the Wild and Scenic Rivers Act ("WSRA") in 1968, the U.S. Congress created a new system of restrictions on those activities intended to protect waterways having certain values worth preserving. The WSRA predates almost all state scenic waterway acts and provided a foundation for many states when crafting their own legislation to protect scenic waterways.[4] The first section of the WSRA declares the policy of the United States as protecting and preserving the free-flowing nature of rivers designated under the WSRA for "the benefit and enjoyment of present and future generations."[5] The WSRA is intended to protect those whose environments possess "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values."[6] The WSRA provides two methods, one through an Act of Congress and the other by State action, for a river to become designated and subsequently included in the National Wild and Scenic Rivers System ("the National System").[7] River designations include: a) wild river area; b) scenic river area; or c) recreational river area, with each class having different levels of protection. Upon entering the National System as a wild and scenic river the most significant results are the federal restrictions concerning construction activities on and around the designated river area.[8]

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[4] Dan Haas, Nat'l Park Serv., *Designating Rivers Through Section 2(a)(ii) of the Wild & Scenic Rivers Act: Technical Report of the Interagency Wild and Scenic Rivers Coordinating Council*, pg 6 (2007), http://www.rivers.gov/publications/2aii.pdf.
[5] 16 U.S.C. § 1271 (2006).
[6] *Id.*
[7] 16 U.S.C. § 1273(a) (2006).
[8] 16 U.S.C. § 1278 (2006).

Designation Methods

The WSRA includes two methods for a river, or a section thereof, to become designated as either a wild, scenic, or recreational river area.[9] The *first*, and most prevalent source of designated rivers, occurs through an Act of Congress and is governed by Sections 4 and 5 of the WSRA.[10] The *second* method of designation is initiated under Section 2 of the WSRA and occurs when a state legislature authorizes a state governor to nominate his/her state's river for consideration by the Secretary of the Interior for admission to the National System.[11] As of June 2009, there were 203 rivers and river segments designated under the WSRA as wild, scenic, or recreational river areas in the United States.[12]

Federal Designation. Congress originally identified 27 rivers for study with the passage of the WSRA in 1968, but today federal designation begins with nominating a river or river segment for study prior to inclusion in the National System.[13] Study nominations are usually initiated at request of local residents and conservation groups, but can also be initiated by individual congressmen or through federal agency identification.[14] A Nationwide Rivers Inventory ("NRI") was created to list rivers, or river segments, that appear to meet the minimum requirements for designation under the WSRA.

A waterway on the NRI provides a minimum level type protection to the waterway areas until a detailed study can be conducted.[15] Currently, more than 3,400 river segments are included in the NRI for potential designation after a WSRA study is conducted.[16] A NRI study is conducted under the jurisdiction of the Secretaries of the Interior and Agriculture and in consultation with other agencies and requires a minimum of one-quarter mile of the nominated river to be included in the study.[17] Upon the study completion the findings are submitted to the President and Congress and if the findings support it, an Act of Congress is ultimately submitted to designate the nominated river or river segment.[18]

Section 2 Designation. In order for a state-nominated river or river segment to be included in the National System, two basic requirements, along with a few other details,

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[9] 16 U.S.C. § 1273(a) (2006).
[10] 16 U.S.C. § 1276 (2006).
[11] 16 U.S.C. § 1273(a)(ii) (2006).
[12] River Mileage Classifications for Components of the National Wild and Scenic River System, http://www.rivers.gov/publications/rivers-table.pdf (accessed May 11, 2011).
[13] Jackie Diedrich & Cassie Thomas, U.S. Forest Serv. & Nat'l Park Serv., *The Wild & Scenic River Study Process: Technical Report of the Interagency Wild & Scenic Rivers Coordinating Council*, 1 & 8 (1999), http://www.rivers.gov/publications/study-process.pdf.
[14] *Id.*
[15] *Id.* at 1.
[16] U.S. Department of the Interior: National Park Service's Nationwide Rivers Inventory, http://www.nps.gov/ncrc/programs/rtca/nri/ (Accessed May 11, 2011).
[17] 16 U.S.C. § 1275 (2006).
[18] 16 U.S.C. § 1276(a) (2006).

must be met.[19] The state must have designated the waterway for protection under state law, and the waterway must meet the values outlined in WSRA.[20] State Section 2 rivers are then afforded the same protection as federally designated rivers with the critical difference being that they are solely administered and paid for by the state, with the exception of federally owned land.[21]

The National Park Service initiates Section 2 designation by assessing the eligibility of the river and then making a recommendation to the Secretary of the Interior.[22] If the Secretary agrees with the designation, the proposed designation is listed in the Federal Register and potentially affected federal agencies are notified.[23] After a 90-day public comment period, the nominated river is designated on the National System if the requirements are met.[24]

The state designation is a much easier path for a river or river segment to enter the National System and it becomes more attractive than federal designation as it leaves states in control to administer the river segment instead of federal agencies.

<u>Classification System</u>. Within WSRA there is a three-part classification system designating river areas as wild, scenic, and/or recreational.[25] The WSRA defines these river areas in the following manner:

> **(1) Wild river areas –** Those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted. These represent vestiges of primitive America.
> **(2) Scenic river areas –** Those rivers or sections of rivers that are free of impoundments, with shoreline or watersheds still largely primitive and shorelines largely undeveloped, but accessible in places by roads.
> **(3) Recreational river areas –** Those rivers or sections of rivers that are relatively accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past.[26]

Each classification prohibits certain activities, for example, construction and water diversions on or in close proximity to set designated waterway that may alter or diminish the values that led to its designation as a wild, scenic, or recreational river area.

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[19] Dan Haas, Nat'l Park Serv., *Designating Rivers Through Section 2(a)(ii) of the Wild & Scenic Rivers Act: Technical Report of the Interagency Wild and Scenic Rivers Coordinating Council*, pg 8 (2007), http://www.rivers.gov/publications/2aii.pdf.
[20] *Id.*
[21] *Id.* at 7.
[22] *Id.* at 4, 8.
[23] *Id.* at 4.
[24] *Id at 5.*
[25] 16 U.S.C. 1273(b) (2006).
[26] *Id.*

Restrictions on Construction Activities

The WSRA restrictions apply to federal agency actions that have adverse effects on those values of the designated river or river segment that are intended to be protected.[27] The Federal Energy Regulatory Committee ("FERC"), for example, "shall not license the construction of any dam, water conduit, reservoir, powerhouse, transmission line, or other project works under the Federal Power Act, on or directly affecting any river [designated under WSRA]."[28] In addition, the WSRA does not allow any department or agency of the United States to "assist by loan, grant, license, or otherwise in the construction of any water resources project" that would adversely effect any of those wild, scenic, or recreational values, that led to the river's inclusion in the National System.[29]

These restrictions mean that federal agency construction in or near designated river areas – as well as agency actions like licensing and loans for non-federal construction operations by private parties – are prohibited if the construction would alter the nature of the designated river area. Private parties can be impacted by restrictions on federal agencies. One example of impact on private parties is the need for a permit under Section 404 of the Clean Water Act. Permits are required for landowners to conduct activities such as dredging or filling a waterway, including wetland areas. Due to WSRA's restrictions, a private party will find it difficult to obtain Section 404 Permitting on any designated river area. At the same time, "licensing of, or assistance to, developments *below or above* a wild, scenic or recreational river area or on any tributary stream," is not precluded as long as the development does not unreasonably interfere with the designated river or river segment values.[30] Unlike some state scenic waterway laws, WSRA focuses little on activities that occur upstream, unless they directly impact downstream river areas.

WSRA in Western States

Western States are generally known for their beautiful rivers and waterways, and also have large numbers of rivers designated as wild, scenic, or recreational areas under WSRA. When the number of designated rivers in Oregon, California, Washington and Idaho are combined, they account for approximately 50% of all National System designated rivers. While the majority of states include at least one designated river or river segment, some states, like Nevada for example, do not have any rivers in the National System.[31] In addition to federal law, by the early 1990s, more than 30 states enacted statutes similar to WSRA protecting more than 13,500 miles of river.[32] All the

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[27] 16 U.S.C. § 1278(a) (2006).
[28] *Id.*
[29] *Id.*
[30] *Id.*
[31] State-By-State Mileage Chart, http://www.rivers.gov/publications.html#reports (Accessed May 11, 2011).
[32] Dan Haas, Nat'l Park Serv., *Designating Rivers Through Section 2(a)(ii) of the Wild & Scenic Rivers Act: Technical Report of the Interagency Wild and Scenic Rivers Coordinating Council*, pg 6 (2007), http://www.rivers.gov/publications/2aii.pdf.

states discussed here have passed legislation similar to the National System with each state having slightly different levels of protection.

Oregon. Oregon is the national leader with a total of 55 rivers and/or river segments designated under the WSRA.[33] For perspective, the state with the second most designated rivers or river segment is Alaska with 25.[34] The Klamath River, which has 297 designated miles, is not included in this or California's totals because it crosses state lines and is treated separately as is the Idaho/Oregon Snake River, at 67.5 designated miles.[35] The total mileage of rivers or river segments designated under WSRA as wild, scenic, or recreational areas in Oregon is 1833.5 miles.[36] Oregon's Scenic Waterway Act provides extensive protection for designated river segments that is far beyond the protections offered by WSRA.

California. Not counting the Klamath River, California has a total of 22 river or river segments that are designated under WSRA and included in the National System.[37] Although not having nearly as many designated rivers as the leading state, California's total mileage is almost equivalent to Oregon's at 1713.4 miles.[38] In addition to WSRA designations, California has its own Wild and Scenic Rivers Act.[39]

Idaho. With a total of 21 river or river segments designated under WSRA, Idaho joins Oregon and California as one of the states with the highest number of waterways included in the National System.[40] The total number of designated miles, while less than half of the previous two states, is still an impressive 822.5 miles of wild, scenic, and recreational river areas.[41] While not having its own scenic waterway act, the Idaho State Water Plan does give the Idaho Board of Water Resources the authority to designate rivers as either natural or recreational waterways.[42]

Washington. Surprisingly, the state of Washington has very few rivers in the National System with only one river in each of the three categories.[43] The total mileage of these three designated rivers is 197.5 miles.[44] Washington, like Idaho, does not have a scenic waterway act but empowers the Washington Department of Ecology with discretionary power to establish minimum stream flows for recreation, fish and wildlife purposes.[45]

[33] State-By-State Mileage Chart, http://www.rivers.gov/publications.html#reports (Accessed May 11, 2011).
[34] *Id.*
[35] *Id.*
[36] *Id.*
[37] *Id.*
[38] *Id.*
[39] Cal. Rev. Code §§ 5093.50 – 5093.70 (2010).
[40] State-By-State Mileage Chart, http://www.rivers.gov/publications.html#reports (Accessed May 11, 2011).
[41] *Id.*
[42] Idaho State Water Plan, Adopted by the Idaho Water Resource Board, p. 82 (Dec. 1996).
[43] State-By-State Mileage Chart, http://www.rivers.gov/publications.html#reports (Accessed May 11, 2011).
[44] *Id.*
[45] Wash. Rev. Code § 90.22.10 (2011).

OREGON'S SCENIC WATERWAY ACT

Oregon's Scenic Waterway Act provides extensive protection for rivers and river segments designated as natural, scenic, or recreational. The SWA was originally applicable only to certain activities within the designated river areas and to surface water appropriations capable of diminishing designated surface water flows. In 1995, the Oregon Legislature expanded the reach of the SWA by prohibiting ground water appropriations that could also result in diminished surface water flows in designated rivers.[46] For example, in order for a finding that a ground water use impacts a designated waterway, the existence of a hydraulic connection between the well site and the potentially impacted waterway must be proven.[47] In addition to the inclusion of ground water, judicial interpretations of the SWA have greatly limited the ability to attain new water rights within river basins that include downstream designated river segments. This expansive interpretation of the SWA has led to the creation of de facto critical ground water areas in many parts of the state that would otherwise only be able to be limited by rulemaking.

Oregon Scenic Waterway Act of 1970

The SWA begins in a manner similar to the WSRA by stating that it is the policy of Oregon to protect the free-flowing character of designated waterways by maintaining water quantities "necessary for recreation, fish and wildlife uses."[48] In addition to protecting water flows, the SWA charges the Oregon Water Resource Commission and the Oregon Water Resources Department to create administrative rules regulating land within ¼ mile from the banks of the designated waterway. This area is called the "related adjacent land." Intended to protect the views of the river area, the administrative rules require landowners to notify the Oregon Parks and Recreation Department ("OPR") of any change to existing use, improvement, or any other activity occurring within the related adjacent lands.[49] A landowner required to give such notice is not permitted to conduct the proposed activity for at least one year after OPR accepts the notice unless OWRD gives approval at an earlier date.[50]

A few example activities that always require notification include cutting of any living tree, road construction, constructing new structures or buildings, and improvements to existing structures and buildings.[51] In addition to notification requirements, each designated waterway has its own individual notification and construction requirements created by OWRD through administrative rules.[52] In order to ensure the scenic beauty of designated waterways, OWRD has authority: a) to obtain a scenic easement to thus control the use of a private property, and b) to use the power of eminent domain to

[46] *Waterwatch of Oregon, Inc. v. Water Resources Commission*, 199 Or. App. 598, 608 (2005).
[47] Or. Rev. Stat. § 390.835(9) (2009).
[48] Or. Rev. Stat. § 390.835(1) (2009).
[49] Or. Rev. Stat. § 390.805(1) (2009), Or. Admin. R. 736-040-0080 (2011), noting that some activities may be exempted under the statute and rule..
[50] Or. Admin. R. 736-040-0080 (2011).
[51] Or. Admin. R. 736-040-0035 (2011).
[52] Or. Admin. R. 736-040-0041 to 736-040-0078 (2011).

purchase any property within related adjacent land.[53] These powers may be used: a) when a landowner is within related adjacent land and the landowner OWRD cannot agree on a proposed alteration; b) the landowner alters property without notifying OWRD; or 3) the landowner alters property while negotiating but before an agreement with OWRD is made.[54]

To maintain surface water flows, no dams or reservoirs are permitted to be built, and no water diversions are permitted *within or above* a scenic waterway except for limited human and livestock uses.[55] The restriction on water diversions also applies to ground water rights of use when the OWRD Director finds a hydraulic connection between the well site and a designated river, and the water use reduces the surface flows necessary for recreation, fish and wildlife.[56] OWRD may issue a new water right of use for human consumption as long as it does not exceed 0.005 cubic feet per second ("CFS"), and for livestock consumption as long as it does not exceed 0.01 CFS per 1,000 livestock.[57] In addition to these maximum amounts of water for domestic or stock watering, OWRD must find that a) the use will not lower flow levels so that interference with recreation, fish and wildlife occurs, and b) the applicant could not find a reasonable alternative source.[58]

> A. For human consumption, OWRD must find that a denial would cause a "loss of a reasonable expectation" of property use. In this instance, OWRD will require the proposed diversion to be monitored and reported[59]
>
> B. For livestock, OWRD must find that the water right of use is necessary to prevent livestock from watering in a designated river area, and that the applicant will exclude livestock from the stream and its adjacent area.[60]

OWRD must consider all *cumulative impacts*, both existing and potential, that issuing the water right may have on the designated river area.[61] The total cumulative surface and ground water use by all users in a designated river area may not exceed *one percent of the daily average flow* or *one cubic foot per second*, whichever is less, unless five separate state agencies unanimously agree that exceeding the lower amount will not lower flow levels necessary for recreation, fish and wildlife.[62]

The cumulative impact rule applies to all ground water right certificates granted *after* July 19, 1995, regardless of how many years it has been since the permit was originally

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[53] Or. Admin. R. 736-040-0085 (2011).
[54] Or. Admin. R. 736-040-0090 (2011).
[55] Or. Rev. Stat. §§ 390.835(1) & 390.835(6) (2009).
[56] Or. Rev. Stat. § 390.835(9) (2009).
[57] Or. Rev. Stat. § 390.835(6) (2009).
[58] *Id*.
[59] *Id.*
[60] *Id.*
[61] *Id.*
[62] *Id.*

granted.[63] This means that a ground water permit granted after July 19, 1995, may be reduced or even revoked *at any time* that OWRD determines it interferes with surface water flows. Finally, OWRD may allow mitigation to prevent any impact of a new water use on the designated waterway but it must "ensure the maintenance of the free-flowing character of the scenic waterway in quantities necessary for recreation, fish and wildlife."[64] Ensuring that mitigation will actually maintain surface flows in designated river areas is relatively simple for surface water diversion but, as is discussed below, can be extremely difficult and complex for ground water appropriations.

<u>Hydraulic Connections</u>

The SWA prohibits new ground water uses that will cause surface flows to drop below amounts necessary to support recreation, fish and wildlife. To establish that a ground water use will decrease surface flows in such a way, the OWRD Director must find that a hydraulic connection exists based upon a *preponderance of the evidence*.[65] It is often difficult to observe and measure the interactions that occur between ground water and surface water when a hydraulic connection exists.[66] These complex interactions between surface and ground water can make it very difficult for governmental agencies, as well as for courts reviewing their decisions, to regulate ground water use as contemplated by the SWA. Despite the complex nature of these interactions, the *preponderance of evidence* standard necessary to prove the existence of a hydraulic connection is *low enough* to allow the OWRD to easily assert jurisdiction and regulate or deny ground water appropriations.

In the context of the SWA, the most important interaction between ground water and surface water is where impacts on stream flows may be seen. "The interaction takes place in three basic ways: streams gain water from inflow of ground water through the streambed, they lose water to ground water by outflow through the streambed, or they do both, gaining in some reaches and losing in other reaches."[67]

When water is pumped out of the ground near a stream, water that would have otherwise discharged into a gaining stream can be intercepted and lower surface flow.[68] If enough water is pumped, a gaining stream can turn into a losing stream and a losing stream can be caused to lose water at a quicker rate.[69] In each case, surface flow rates can be adjusted, but due to the length of time for such changes to become apparent, it makes regulating ground water difficult for governmental agencies. Depending on from what depth the ground water is pumped, the quantity of water actually pumped, and the nature of soil in the area, the time factor becomes apparent and can range from

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[63] Or. Rev. Stat. § 390.835(9)(g) (2009).
[64] Or. Rev. Stat. § 390.835(10) (2009).
[65] Or. Rev. Stat. § 390.835(9) (2009).
[66] Thomas C. Winter, et al., *Ground Water and Surface Water: A Single Resource*, U.S. Geological Survey Circular: 1139, 1 (1998).
[67] *Id.* at 9.
[68] *Id.* at 11.
[69] *Id.*

months to years to decades.[70] Such lengthy time periods make it difficult for a ground water use applicant to prove, or propose, acceptable mitigation. Replacing water removed from the stream via hydraulic connection, *at the correct time*, is required by SWA, but likely requires a hydraulic study.

Judicial Interpretation and Expansion of Protected Areas

Since the passage of Oregon's SWA in 1970, judicial interpretation concerning the breadth of protected areas has expanded to include areas well beyond the actual designated river areas. One of the most significant of these occurred in 1988, when the Oregon Supreme Court expanded the SWA's reach to all streams that are *tributaries* to designated waterways in a case called *Diack v. City of Portland* ("Diack").[71] With the inclusion of ground water under the SWA in 1995, *Diack* requires that all hydraulically connected ground water appropriations within the same basin containing downstream designated river areas, meets the requirements of the SWA.[72] Regulating new ground water appropriations in a way that complies with the SWA is extremely complex and difficult for governmental agencies to achieve.

The *Diack* Expansion. In *Diack*, the City of Portland was granted a permit from the OWRD to divert water from the Bull Run Watershed at a location just above a 12.5 mile stretch of the Sandy River which was designated under the SWA.[73] Typically, no issue would have existed in granting Portland's permit; however, Bull Run River flows are implicated by the Sandy River designation under the SWA because Bull Run is a tributary to the Sandy River.

Under *Diack*, and under the request permit, water being diverted from Bull Run would return to the Columbia River, thus bypassing the lower Bull Run River and the Sandy River entirely.[74] OWRD found that the SWA applied to Portland's diversion but concluded that the diversion from Bull Run would prevent the maintenance of minimum flow levels in the Sandy River.[75] Ruling in favor of Portland, the Oregon Court of Appeals concluded that the SWA was not applicable to diversions outside the scenic waterway, but added that OWRD still had to maintain necessary flow levels.[76]

The Oregon Supreme Court, taking issue with the appellate Court's decision, concluded that "no diversion of water that otherwise would enter a scenic waterway may be permitted unless the requirements of [the SWA] are met."[77] The Court noted that this finding did not occur.[78] Portland's permit was revoked as the technical requirements of

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[70] William M. Alley, et al., *Flow and Storage in Groundwater Systems,* Science Vol. 296, 1985, 1990 (2002).
[71] *Diack v. City of Portland*, 306 Or. 287 (1988).
[72] *Waterwatch of Oregon, Inc. v. Water Resources Commission*, 199 Or. App. 598 (2005).
[73] *Diack v. City of Portland*, 306 Or. 287, 290 (1988).
[74] *Id.*
[75] *Id.* at 292.
[76] *Id.* at 291.
[77] *Id.* at 298.
[78] *Id.*

the SWA were not met. The Court's conclusion that the SWA applies to all water that eventually ends up in a designated waterway placed expansive restrictions on the availability of future water rights originating from upstream waterways.

Hydraulic Connections are Difficult. In 1995, the Oregon Legislature expanded the reach of the SWA to include ground water rights.[79] OWRD attempted to create administrative rules governing mitigation of ground water permits but the rules were challenged by Waterwatch of Oregon.[80] The lawsuit that followed was decided in 2005, *Waterwatch of Oregon, Inc. v. Water Resources Commission*, and is an excellent example of how the complexity of hydraulic connections between surface water and ground water can frustrate attempts to regulate ground water withdrawals as contemplated under the SWA.

The main issue in *Waterwatch* was whether or not OWRD's rules governing ground water permit mitigation would actually "maintain" the flows to ensure quantities necessary for recreation, fish and wildlife.[81] A ground water right may be granted even if it lowers surface water flows in the reach of hydraulically connected designated waterways, *so long as the impact is mitigated by the applicant*.[82] *Waterwatch* determined that state statutory obligations required OWRD to deny all applications for ground water permits unless the mitigation fully offset impacts on surface flows in scenic waterways.[83] OWRD had attempted to comply with the SWA by requiring a ground water applicant to return a volume of water equal to any consumptive use to the hydrological system, as well as annual monitoring to ensure successful mitigation.[84] At first glance, OWRD's rule seemed to meet the requirement to offset impacts of ground water use on scenic flows. However, the rule was found to be inadequate as the complex nature of hydraulic connections was not accounted for.

The mitigation rule crafted by OWRD did not guarantee that impacts to surface water flows would be offset for two reasons. *First*, the Court points out that OWRD's rule amounted to a requirement of maintaining yearly *average* volumes of water in the waterway.[85] Maintaining an annual average volume does not ensure that flow levels are kept at the required amounts to support recreation, fish and wildlife.[86] Annual averaging is not appropriate. Fish populations are constrained by low flow periods and average measurements mask the lowest flow periods.[87] In other words, a designated stream may dry out for a few days, killing all the fish, but the average volume of water in the stream could still be higher than the level set by the OWRD.

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[79] *Waterwatch of Oregon, Inc. v. Water Resources Commission*, 199 Or. App. 598, 608 (2005).
[80] *Id.* at 601.
[81] *Id.*
[82] *Id.* at 606 (citing Or. Rev. Stat. § 390.835(9)(a)).
[83] *Id.* at 607.
[84] *Id.* at 613.
[85] *Id.* at 614.
[86] *Id.*
[87] *Id.*

Second, the OWRD rules did not account for lengthy time periods between ground water withdrawal and impacts on surface flow levels. "The impacts of ground water withdrawals on surface flows may not occur for years."[88] The rules that require mitigation water to return to the system in the same year the ground water is withdrawn, do not ensure that enough mitigation water will be available to replace the withdrawn ground water when the withdrawal actually begins to impact the surface water flows, which may occur years later.[89] The Court points out, "[t]he fact that there is a complex relationship between ground water appropriations and surface flows that is difficult to measure does not excuse compliance with the statutory requirement that flows be maintained."[90] The Court opines that OWRD's position is akin to OWRD "not knowing the consequences of issuing ground water permits under the rules but [is] engaging in an experiment to find out."[91] The Court's decision that OWRD's rules are inadequate in this case, despite the good-faith effort to comply with SWA requirements, illustrates how difficult it is to balance water resource uses with the desire to ensure that scenic waterways will continue to provide benefits to future generations.

THE GRANDE RONDE RIVER BASIN[92]

The Grande Ronde River Basin (the Basin) includes three river segments designated under Oregon's SWA and the federal WSRA. This means all three designated river areas have restrictions under the federal Act as well as the more expansive state Act restrictions. The three river segments include: the Minam River from Minam Lake to the Wallowa River, the Wallowa River from its confluence with the Minam to its confluence with the Grande Ronde River, and the Grande Ronde River from its confluence with the Wallowa River to the Oregon-Washington border.[93] *See attached map*. The Grande Ronde River and the Minam River were both originally designated under Act of Congress in 1988 with the former composed of a 43.8 mile segment and the later a 39 mile segment.[94] The Wallowa River segment, at 10 miles in length, entered the National System through Section 2 of the WSRA under Oregon state nomination it in 1996.[95]

The amount of surface water required to fulfill quantities under the SWA that ensure recreation, fish and wildlife uses, is established by OWRD for each designated waterway. Flow assessment for the three river segments were conducted in the early 1990's.[96] The flows required for recreation are determined separately from the flows required for fish and wildlife. Whichever is the higher of the two flows is the required

[88] *Id.* at 614.
[89] *Id.*
[90] *Id.* at 615.
[91] *Id.*
[92] *See Attachment A* for a map showing the location of Oregon's Scenic Waterways.
[93] Or. Rev. Stat. §§ 390.826(12) & (13) (2009).
[94] State-By-State Mileage Chart, http://www.rivers.gov/publications.html#reports (Accessed May 11, 2011).
[95] *Id.*
[96] OWRD Memorandum: Request for approval of Grande Ronde, Wallowa, Minam, and Owyhee Rivers scenic waterway flows for *Diack* findings (1992).

amount.[97] The flows were set by interviews with local fisherman, boaters, agency personnel, recreation resource specialists, boating publications, and fish and wildlife publications from Oregon Department of Fish and Wildlife.[98] The SWA requires that surface flow rates must be maintained once they are established by OWRD. To make the required flows more suspect, determining when a threshold is met is not based upon actual flow measurements but by adding up the full rates of existing water rights that hold a legal right to use either directly or indirectly (as determined by an agency staffer) from the waterway in question. Such totaling does not account for rotation, crop patterns, certificates or permits that are in non-use or other such factors. The calculations are simply "on paper."

According to OWRD, this threshold relating to ground water impact on surface was reached on the Grande Ronde in January of 2006.[99] OWRD determined that the *cumulative impact* threshold under SWA is the lower of either: 1% of average daily flow, or 1 cubic foot per second. From the moment of cumulative impact determination, OWRD is no longer allowed to grant any more ground water permits in the SWA Basin *unless* the impacts on surface flows are fully mitigated.[100]

As noted above under *Waterwatch*, OWRD has yet to successfully create a rule to govern mitigation that meets statutory requirements as set out in the SWA. Thus it is highly unlikely that any ground water permits will be granted where a well is, or is likely to be, hydraulically connected to any surface water within the SWA Basin. The only other option for new ground water use in the Grande Ronde Basin is to drill deep enough to reach deep bedrock aquifers that are not hydraulically connected to surface water.[101]

Other river basins containing segments of SWA rivers will inevitably reach the cumulative impact thresholds thus creating more de facto critical ground water areas in the State. Applications for new ground water appropriations (like in the Grande Ronde River Basin) will unlikely gain approval.

CONCLUSION

Increased environmental protection created through the Scenic Waterway Acts has led to unexpected consequences by affecting the ability to obtain new ground water permits. The federal Wild and Scenic Rivers Act began the process by prohibiting all federal construction, licensing of private party construction, and other activities dependent on federal approval *that could alter the wild, scenic, or recreational character* of designated river segments. The National Rivers Inventory has over 3,400 rivers or river segments with characteristics that could be designated to receive federal

[97] *Id.*
[98] *Id.*
[99] Douglas Woodcock, OWRD Memorandum to OWRC: Informational Update on Scenic Waterway Evaluations with Respect to Ground Water in the Grande Ronde Basin, Oregon (February 2007).
[100] *Id.*
[101] *Id.*

protection. In addition, many states quickly followed the federal example and passed analogous legislation creating the ability for state designated river segments with similar or even greater protections. The Grande Ronde River Basin in Oregon is an example where a combination of extensive state protection and judicial interpretation of Oregon's Scenic Waterways Act has led to a denial of all new ground water applications. As demands for water continue to increase, along with population and economic growth, many landowners within protected river areas will likely face similar restrictions on surface and ground water use in the near future.

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TILE DRAINAGE — THE SOURCE OF ADDITIONAL IRRIGATION WATER AND SUSTAINABLE CROP PRODUCTION: A CASE STUDY OF FARMER AND AGENCY-MANAGED SYSTEMS IN SINDH, PAKISTAN

Bakhshal Lashari[1]

ABSTRACT

To examine whether re-using agricultural affluent has environmental risks for crop irrigation, the potential for providing an additional source of irrigation water and of the impact of institutions (farmer and agency), a study was conducted on farmer- managed and agency-managed tile drainage systems in Sindh Pakistan.

Re-using drainage water on the farmer- managed tile drainage system, for 18 years from 1988-2006, resulted in the soil salinity improving from 32.32 dS/m to 3.18 dS/m, water quality of the re-used water improving from 38 dS/m to 4.58 dS/m, provision of 12-15 percent additional irrigation water, increasing crop intensity from about 40 percent to more than 100 percent and improving the cost benefit ratio from 0.114 to about 1.42.

Re-using drainage water on the agency-managed tile drainage system was problematic as the system was dysfunctional for more than 55 percent of the time because misuse of O&M funds. Water table fluctuated frequently from 0.12 m to 1.43 m. Recycled water quality, remained within 2.7-3.0 dS/m. Further, filed trials with various water management applications such as: A1 (canal water), A2 (recycled water), A3 (alternate irrigation) and A4 (blended water 85% recycled and 15% canal water) illustrated that recycled water did not produce good yields in any crops, whereas, alternate irrigation and blended water produced good yields in cotton, wheat and alfalfa crops. In forest plants results indicate that forest plants planted by seed germinated but progressively failed to survive or germinated well in year one but subsequently about 10-30% plants died because of high water table.

The study concluded that farmer-managed tile drainage systems are a better approach to ensure functional drainage systems, increased crop production and reduced environmental risk. In contrast, agency-managed system fails to provide benefits from re-using drainage water.

INTRODUCTION

Scarcity of conventional sources of waters in arid and semi-arid regions has promoted the search for additional sources (that is, unconventional or marginal waters), such as deep groundwater, treated wastewater, and brackish water. Saline water comes in the form of drainage water from agricultural fields. Using saline water can result in limited agricultural yields, but improved product quality (Pasternak and DeMalach 1987). Using treated wastewater for agricultural irrigation is attractive for a series of invaluable consequences (Gamble 1986; Chang et al. 1990). Domestic treated wastewater is a fairly

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stable water source and has uses in agriculture, industry, recreation, gardening, industrial-plant cooling, and recharge of groundwater (Cromer et al. 1984; Oron et al. 1986; Burau et al. 1987; Asano and Mills 1990; Campos et al. 1998).

Where people have advanced irrigation technologies and water-harvesting, they often use these additional sources of water to reduce demand and satisfy water requirements. Furthermore, droughts, which often occur in dry regions, amplify water management problems and require long-term measures to reduce the vulnerability of water systems and short-term measures to mitigate impacts of the drought. Water-resources management in arid and semi-arid regions is a complex, multifaceted task, because of the need to integrate many hydrological, environmental, economic, social, and managerial factors. The holistic approach is appropriate to provide all users of diverse sectors sufficient supplies of adequate water while ensuring environmental protection. Using treated wastewater for agricultural irrigation is attractive for a series of invaluable consequences (Gamble 1986; Chang et al. 1990). Disposal of large amounts can occur throughout the year, with or without storage (under distinct circumstances, the storage can be an extra treatment phase), with minimal environmental risk (Shelef 1991; Oron et al. 1992; Juanico and Shelef 1994); and Economic benefits due to the nutrients make the effluent a better fertilizer Neilsen et al. 1989).

In areas where irrigation water is scarce, the re-use of drainage water is an important strategy for supplementing water resources. Furthermore, reuse helps alleviate drainage disposal problems by reducing the volume of drainage water. The reuse of drainage water for irrigation can reduce the overall problems of water pollution. Reuse measures consist of: reuse in conventional agriculture; reuse to grow salt tolerant crops; reuse in wildlife habitats and wetlands; and reuse for initial reclamation of salt-affected lands.

Drainage water is normally of inferior quality as compared to the original irrigation water. Adequate attention needs to be paid to management measures to minimize long-term and short-term harmful effects on crop production, soil productivity and water quality at project or basin scale. The drainage water quality determines which crops can be irrigated. Highly saline drainage water cannot be used to irrigate salt sensitive crops, but it can be used on salt tolerant crops, trees, bushes and fodder crops. A major concern in reuse measures are that drainage water from reused waters is often highly concentrated, requiring careful management.

This study investigates the effect of reusing drainage water on the soil environment, crop productivity and growth of forest plants. under two different management systems: agency-managed and farmer-managed tile drainage systems

STUDY AREAS

The study areas were at Nawazabad Farm (farmer managed system) and Bareji Distributary command area –tile drainage unit SL12 (agency managed system), both of which are located in the command area of Jamrao Canal of Sukkur Barrage (see Figure 1). The farmer managed system covers an area of about 100 acres and agency managed system covers an area of about 540 acres. Monitoring of data on farmer managed system was partly done by Drainage and Reclamation Institute of Pakistan (DRIP) and partly done by a Master's student of the Institute of Water Resources Engineering and Management.

The farmer managed system was initiated by DRIP in collaboration with farmer in 1988 on cost sharing basis. This was pilot project to see the benefits of farmer's participation for sustainable management of the system. DRIP was collecting the relevant data such as water table depth, soil salinity, water quality, cropping intensity and yield. In year 2006, the Institute of Water Resources Engineering and Management engaged one M.E student in collecting the data for the purpose to investigate the trends of all the parameters. Thus this paper included all the data from 1995 to 2006.

The agency managed system was monitored from 2009-2010 under the project sustainable reuse of drainage effluent for crop production sponsored by World Wide Fund (WWF), Pakistan. Along with monitoring the system some trials were made to investigate the impact of recycled water on crop productivity and soil environment. For this purpose about 5 acres of land, which was partly barren for years, was used for the study area. On three acres of land, three plants species i.e., Neem (Azadirecate indica), Babbur (Acacia nilotica) and Manjhlee (Sesbania aegyptica) were planted (each species on one acre of land) and, on the remaining two acres of the land, field crops i.e., wheat and alfalfa in Rabi (Winter) season and cotton and Jantar (Sesbania sesban) in Kharif (Summer) season were cultivated.

Both tile drainage units receive significant seepage water from the main canals which run close to the systems.

Field trial setup and data collection

After land preparation, the study area on the agency-managed system was divided into five portions. The Neem, Babbur and Manjhlee were planted on bed and furrows method. The Neem and Babbur were transplanted while Manjhlee was propagated through seeds. The wheat, cotton and alfalfa were cultivated on flat bed. The setup of the plot was made through a complete Randomized Block Design (see Figure 2). The five irrigation treatments (T) were adopted. T_1 - irrigation with canal water (control), T_2 - irrigation with recycled water, T_3 - alternate irrigation: canal water and recycled water, T_4 - recycled water blended with 15 percent of canal water and T_5 –recycled water blended with 25 percent of canal water. Each treatment was replicated thrice to take account of soil/fertility variations.

Soil and water samples were collected before and after the crop season. The soil samples were collected at the depth of 0-15cm, 15-30 cm, 30-60cm and 60-90cm. Irrigation water was applied as per crop water requirement and was measured using a Cut Throat Flume. The water table depth was measured periodically, growth of agro-forestry plants was recorded on monthly basis and yields of field crops were noted down at the end of the season.

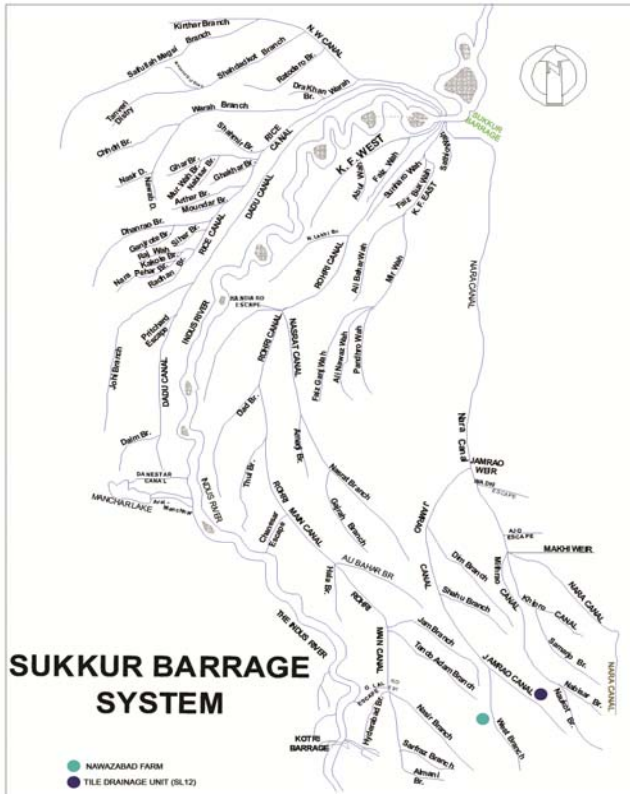

Figure 1. Location Map of the Study Areas.

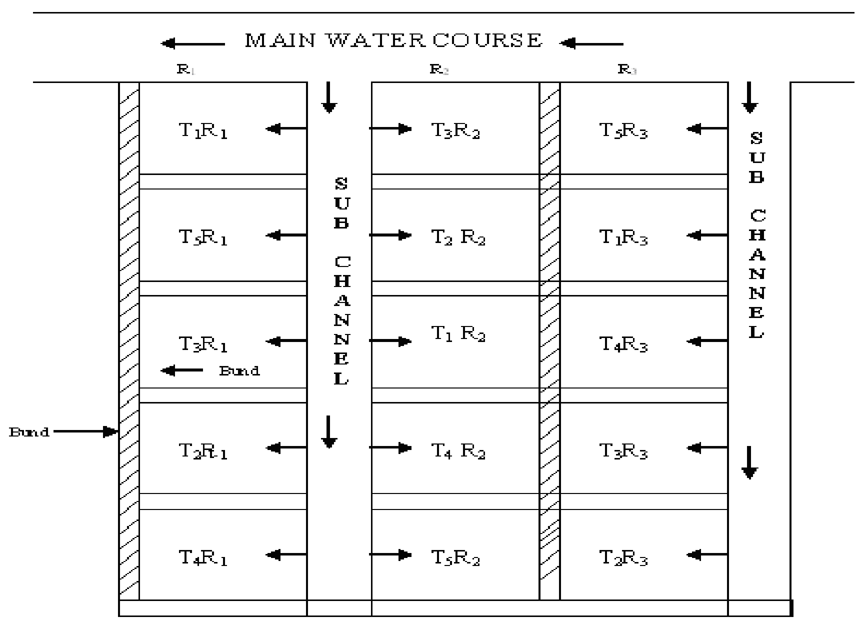

Figure 2. Randomized Block Design for Field Trials.

RESULTS AND DISCUSSIONS

Farmer managed tile drainage system

Re-using drainage water on the farmer managed tile drainage system over 18 years resulted in the system performing well. The soil salinity level lowered down from 32 dS/m to 4 dS/m, water quality improved 38 dS/m to 4 dS/m and water table depth remained within safe limit of 1.4 m (see Table 1)

Table 1. Soil Salinity, Recycled Water Quality and Water Table Depth in the Nawazabad Farm.

Soil salinity (dS/m)					Water quality (dS/m)				Average water table depth (m)			
Sampling depth (cm)	Pre-project	Post project			Pre-project	Post project			Pre-project	Post project		
	1988	1995	2000	2006	1988	1995	2000	2006	1988	1995	2000	2006
0 - 15	32.32	6.52	4.58	3.18	38	5.4	3.73	4.58	0.5	1.13	1.39	1.4
15 - 30	30.40	6.15	4.05	3.62								
30 - 60	20.83	5.88	3.95	3.43								
60 - 90	26.66	5.90	3.99	3.85								
90 - 120	20.40	5.50	3.50	4.36								

The economic benefit started after the first year of the project implementation. The cropped area increased from 40 acre to ultimately 100 acres (100%) and the cost-benefit ratio reached 1.42 (see Table 2). The tile drainage system is very close to the main canal and receives significant seepage water from the canal. Approximately 12-15 percent of the drainage water was irrigation canal seepage water. Further, it was also noted that when water was short by 30-40 percent and supplies in canals were rotated, it was possible to continue irrigating the tile drainage command area using this 12-15 percent seepage water. This additional water played a major role in improving the benefit-cost ratio and sustainable agriculture especially in the area where water shortage was 30-40 percent.

Table 2. Cost- Benefit Ratio at Nawazabad Farm.

Year of assessment	Cropped area (acre)	Fallow land (acre)	Cultivation and drainage cost (PKRs)	Output (PKRs)	Net benefit (PKRs)	Net benefit PKRs/acre	Benefit-cost ratio
1988	40.5	59.5	95380	106300	10920	270	0.11
1989	60	40	160100	369646	209546	3492	1.31
1990	68	32	161594	391214	229620	3377	1.42
1991	74	26	220961	446019	225058	3041	1.02
1994	88	12	271128	597087	325959	3704	1.20
1995	100	0	253835	439250	185415	1854	0.73
2000	100	0	201260	470500	269240	2692	1.34
2006	100	0	344800	769600	424800	4248	1.23

Note: US$ 1= PKRs.61 (Year 2008)

Agency managed tile drainage system

Agency-managed tile drainage unit SL12 was dysfunctional for about 55 percent of time during the one-year observation due to the lack of O&M or mis-use of funds. This resulted in the water table fluctuating frequently between 0.12 m to 1.47 m(see Figure 3). Furthermore, for about 60 percent of the time, the water table depth remained below 1.0 m against the designed depth of about 1.8 m. Operation and maintenance issues were discussed with agency staff several time , but they were unable to sort out the problems.

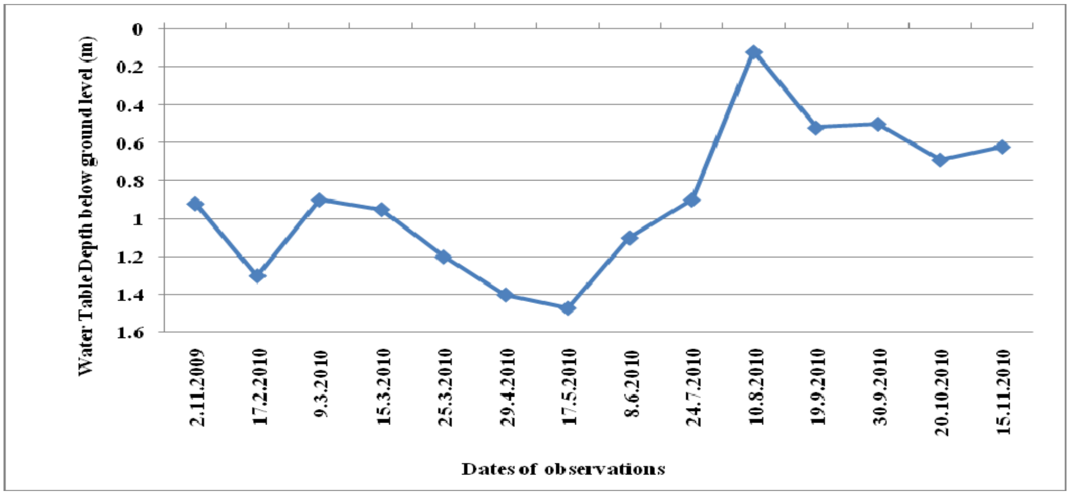

Figure 3. Water Table Depth Below Ground Level

As per design this tile drainage unit SL12 (Agency managed system) approximately generates 2.5 cusecs of recycled water. The quality of this recycled water, recorded two times, was between 2.7 to 3.0 dS/m which was considered marginal quality and suitable for blending with canal water with 1:1 ratio (see Table 3). But due to non-functioning of the drainage system, the benefit of this additional source of irrigation water was not fully utilized, even when the irrigation system was closed for about 30-40 percent of time due to canal water shortages. The scope for using drainage water during shortages of irrigation water was shared with farmers as well as with agency staff but due to the lack of coordination among users and misuse of O&M funds, the benefits could not be realized

Table 3.Water Quality of Recycled and Canal Water in Tile Drainage Unit SL12.

Observation dates	Kind of water	Parameters			Water quality
		ECw (dS/m)	pH	SAR	
31.10.09	Canal	0.29	7.3	1.44	Good
31.10.09	Recycled	2.93	7.7	4.39	Marginal
29.04.10	Canal	0.43	7.1	1.2	Good
29.04.10	Recycled	2.77	7.3	4.1	Marginal

Table 4. Soil Status Before Sowing in the Study Area of Tile Drainage Unit SL12.

Sample No.	Sampling depth (cm)	Texture	ECe (dS/m)	pH	SAR
1. Neem plot					
1	0-15	Silt Loam	15.6	7.5	17.5
2	15-30	Sandy Loam	16.7	7.3	12.9
3	30-60	Loamy Sand	17.0	7.3	12.8
4	60-90	Loamy Sand	17.8	7.5	13.0
2. Babbur plot					
1	0-15	Silt Loam	16.0	7.3	10.8
2	15-30	Very fine Sandy Loam	17.2	7.4	11.4
3	30-60	Loamy Sand	17.0	7.5	11.8
4	60-90	Silt Loam	16.8	7.4	12.0
3. Manjhlee plot					
1	0-15	Sandy Loam	28.0	7.5	18.0
2	15-30	Silt Loam	26.2	7.5	18.6
3	30-60	Sandy Clay Loam	33.0	7.8	22.3
4	60-90	Loamy Sand	22.4	7.4	16.1
4. Wheat plot					
1	0-15	Silt Loam	15.0	7.3	11.0
2	15-30	Silt Loam	16.2	7.2	13.4
3	30-60	Sandy Loam	16.8	7.2	13.9
4	60-90	Silt Loam	17.0	7.3	11.9
5. Alfalfa plot					
1	0-15	Silt Loam	14.8	7.3	9.7
2	15-30	Loamy Sand	15.0	7.2	12.1
3	30-60	Silt Loam	14.6	7.4	12.2
4	60-90	Loam	16.1	7.4	11.5

Table 5. Soil Status After Field Trials in the Study Area (Sept 2009-May 2010).

Application	Sampling depth (cm)	ECe (dS/m)	pH	SAR
Wheat crop				
A_1	0-15	13.5	8.4	6.5
	15-30	13.1	8.5	7.5
	30-60	13.3	8.5	6.0
	60-90	7.2	8.4	5.1

A_2	0-15 15-30 30-60 60-90	14.0 13.8 8.0 7.8	8.4 8.5 8.4 8.3	6.2 4.9 5.1 4.9
A_3	0-15 15-30 30-60 60-90	12.8 11.9 15.3 7.5	8.3 8.2 8.4 8.3	9.9 6.3 5.9 5.1
A_4	0-15 15-30 30-60 60-90	13.3 13.2 7.8 7.8	8.3 8.5 8.3 8.4	5.8 5.1 6.0 6.2
A_5	0-15 15-30 30-60 60-90	15.1 14.7 14.8 13.9	8.5 8.6 8.5 8.6	7.8 8.1 5.3 6.0
Alfalfa crop				
A_1	0-15 15-30 30-60 60-90	18.2 17.5 14.2 17.8	8.6 8.7 8.5 8.5	10.3 7.9 6.8 16.5
A_2	0-15 15-30 30-60 60-90	18.2 18.5 15.1 7.8	8.2 8.3 8.4 8.5	5.8 6.0 6.0 6.2
A_3	0-15 15-30 30-60 60-90	20.2 17.1 16.5 16.8	8.6 8.7 8.7 8.6	15.9 13.9 12.2 11.8
A_4	0-15 15-30 30-60 60-90	17.8 15.3 18.1 17.8	8.3 8.4 8.6 8.6	6.5 5.8 8.2 7.9
A_5	0-15 15-30 30-60 60-90	14.5 13.9 18.5 14.1	8.3 8.4 8.6 8.7	8.1 6.5 13.2 9.0

Tables 4 and 5 reveal that the soil before crop sowing was moderately saline (ECe 8 – 17 dS/m) at all five sampling depths. After set up of field trials and cultivation/harvesting of wheat and alfalfa crops, soil samples were collected and analysed. It was found that the ECe, pH and SAR in all five treatments decreased but the decrease was at low level (Because of moderately saline soil this land was being occasionally used by the farmer for agriculture purposes).

The immediate impact of reuse of saline water on this soil with different water use applications was not significant, even fresh water application did not bring any change in soil salinity. This is most probably due to non-functioning of the tile drainage unit for about 55 percent of time. As discussed, the water table depth fluctuated between 0.12-1.47 m and thus the leaching process was ineffective. It is therefore concluded that the change in the soil status may occur after 3-4 cropping seasons if the unit functions effectively. Nevertheless, the use of marginal recycled water to irrigate wheat and alfalfa crops increased the crop productivity.

Table 6. Yield of Different Crops by Various Water Use Applications.

	Wheat (Kg/ha)	Cotton (Kg/ha)	Jantar (T/Ha)	Alfalfa (T/ha)
A1	2597.7	2922.6	18.4	44.7
A2	1293.3	1831.7	9.8	7.5
A3	2004.2	2747.5	17.2	38.7
A4	1534.6	2040.4	13.3	11.6
A5	1702.2	2107.7	13.8	22.0

Note: In Pakistan, the average yield of wheat is 3500 Kg/ha and cotton is 4051 kg/ha.

Table 6 shows the water use applications such as: A1 (canal water), A2 (recycled water), A3 (alternate irrigation) A4 (blended water 85% recycled and 15% canal water) and A5 (blended water 75% recycled and 25% canal water). Results illustrate that in the wheat crop the recycled water irrigation (A2) produced 50% less yield in comparison to canal water (A1). The alternate irrigation (recycled and canal water - A3) produced 23% less yield and blended water (A4) produced 41% less yield and A5 produced 28% less yield in comparison to canal water. Similar trends were observed in cotton and fodder crops (Jantar and Alfalfa). It is therefore concluded that re-using inferior quality drainage water may help to increase crop production without damaging the soil and can be used as supplementary irrigation water to overcome the water shortages especially in arid to semi-arid regions like Sindh Province of Pakistan. Furthermore, the yield of the wheat, cotton and fodder crops was recorded low as compared to average yield of Pakistan. The reasons of low yield were: poor soil conditions, water table depth fluctuations, rotational closure of the canal and non-functioning of the drainage system.

Table 7. Growth and Survival Rate of Forest Plants

	Growth: June- November 2010 (cm)		Survival rate (%)	
	Neem (Acacia nilotica)	Babbur (Azadirachta indica)	Neem (Acacia nilotica)	Babbur (Azadirachta indica)
A1	136	130	90	83
A2	98	61	77	77
A3	108	89	93	80
A4	94	84	73	70
A5	100	85	73	73

Three forest plant species Acacia nilotica (Local name: Neem), Azadirachta indica(Local name: Babbur) and Sesbania egyptica (Local name: Manjhlee) were planted. The same water use applications were applied. Results indicated that seeds of Sesbania egyptica germinated but progressively failed to survive. The growth of Azadirecta indica was recorded maximum under A_1 : 136 cm (27 cm/month) and followed by A_3 : 108 cm (21.6 cm/month), A_5 :100 cm (20 cm/month), A_2 :98 cm (19.6 cm/month) and A_4 : 94 cm (18.8 cm/month) in five months period. The same trend was also recorded in the case of Acacia nilotica plants. Although, these two species germinated well in year one in all five water use applications later 10-30 percent plants died because of water table fluctuation (see Table 7). In spite of slow growth under A_2, A_4 and A_5, the saline land and recycled (saline) water of tile drainage unit could be used successfully for afforestion. This will certainly add to the income of farming communities on one hand and help sustain their agricultural livelihood.

LESSONS LEARNED

Farmer managed tile drainage unit was mostly well maintained and kept targeted achievements of installation of the system, though they needed technical support all along the way which they were able to get from the company or organization that helped them to install the system.

Agency managed tile drainage system was always facing problems of its maintenance, required funds for the maintenance and the proper use of maintenance funds. Most and critical issue was the frequent transfer of the technical staff and lack of interest. There was also lack of coordination among the stakeholders especially farmers and management staff that resulted in poor performance of the system.

Unfortunately, the farmers and agency gave least priority to agricultural drainage in comparison to irrigation system and other agricultural inputs, though several awareness workshops were organized for the farmers at the field to acquaint them with the advantage and benefits of the drainage system.

SUMMARY AND CONCLUSIONS

The study conducted on two isolated tile drainage units; one farmer managed and another agency managed system. These units were very close to the main canals and were receiving significant seepage water from the canals that accounted for approximately 12-15 percent of the drainage water. Due to the proper functioning of farmer managed drainage system, this additional water was used to complement irrigation canal water especially when canals were rotated due to water shortages which happened about approximately 30-40% of the time. Utilization of the seepage water from the canal was the major reason for improved the cost-benefit ratio. Further, the farmer managed system has been mostly functional and achieved targeted objectives of the system including crop productivity, soil environment, supplement irrigation and above all sustainable agriculture and rural livelihood and food security. Whereas, the agency managed drainage system was non-functional for about 55 percent of the time during the first year of the study, resulting in the water table fluctuating between 0.12 m to 1.43 m below ground level which contributed to the crop production and yield not improving significantly.

Various water use applications trials (recycled and fresh canal water) were carried out and the impacts analysed. The crop trials showed that the yields of recycled water blended with canal water and rotational trials were closed to canal water. These water use applications generated about 50 to 85 percent extra water to supplement canal water for more cultivation of land, though the yield was less as compared to fresh water, but it is expected that the water quality would improve in 3-4 crop seasons and more yield increase is anticipated. Furthermore, the yields of the wheat, cotton and fodder crops were low as compared to average yield of Pakistan. This is due to poor soil conditions, water table depth fluctuation, rotational closure of the canal and non-functioning of the system.

The same trials were conducted for forest plants: Acacia nilotica (Local name: Neem), Azadirachta indica (Local name: Babbur) and Sesbania egyptica(Local name: Manjhlee). Sesbania egyptica was planted by seed and germinated but progressively failed to survive. Azadirecta indica and Acacia nilotica plants in all five treatments germinated well in year one but later 10-30 percent plants died because of water table fluctuation. If water table were fully controlled then these plants would have certainly survived 100 percent.

Finally, the study concluded that farmer-managed tile drainage system is the best approach to ensure the functioning of drainage systems so that drainage water can be re-used to crop production and yields and minimize environmental risk. In contrast, agency managed systems fail to achieve these benefits. . Therefore, it is suggested that tile drainage systems should be managed by farmer communities to maximise the potential benefits of drainage systems and ensure their sustainability.

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AQUA-CIDES: TO PERMIT OR NOT TO PERMIT, THAT IS THE QUESTION

Sarah R. Liljefelt, J.D.[1]

ABSTRACT

Pesticides are widely used throughout the United States and the world. In the United States, there has been much confusion as to whether the Clean Water Act impresses regulation on the application of pesticides. The Clean Water Act imposes certain permitting requirements on "discharges of pollutants to waters of the United States," but whether those permitting requirements are relevant to certain pesticide applications has been the source of heated debate as of late. Recently, the courts and executive agencies have clarified how pesticide applications to water should be treated and what requirements apply … sort of!

This paper briefly discusses pesticides use, the mandates of the Clean Water Act, pesticide control (or lack thereof) under the Clean Water Act in the 21st Century, and recent developments in this area of the law. Finally, this paper examines the impacts of such changes, including the direct and cross-over implications on the pesticides regulatory system.

DISCUSSION

<u>The Use of Pesticides & Herbicides in and over Waters</u>

"Pesticides" is a broad term. It includes insecticides, herbicides, fungicides and additional substances used to control unwanted pests. Since World War II, the use of pesticides has become very widespread in the United States, and in the world.

Pesticides are applied for a variety of useful purposes, including controlling insects that are vectors for disease, curbing the spread of invasive species, eliminating overgrowth of plants in irrigation canals and more. However, because pesticides are designed for the purpose of killing targeted species, they can have harmful effects on non-target species as well, and can create unexpected results if combined with other substances. Pesticides may also be persistent in the environment and within the bodies of subjects that ingest the substances.[2] It is for these reasons that pesticides are heavily regulated.

Pesticides are often applied to water, either intentionally or unintentionally. Direct pesticide applications to water are routinely conducted to target species within waters.

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[2] The USGS reports that across the United States, conventional water treatment does not completely remove pesticides from finished drinking water. However, levels are generally below EPA standards. USGS, *Pesticide Occurrence and Distribution in the Lower Clackamas River Basin, Oregon, 2000-2005*, Scientific Investigations Report 2008-5027 44 (2008).

Indirect pesticide applications to water may occur from targeting pests above or near waters. Finally, unintentional applications may occur from pesticide drift through the air, or runoff from adjacent lands.

In the 21st Century, a debate began regarding federal and state regulation of pesticides; specifically, whether pesticide applications to waters should come within the requirements of the Clean Water Act. Additionally, which pesticides, and to what end?

The Clean Water Act & NPDES Permitting

The Clean Water Act. The CWA was originally passed in 1948 as the Federal Water Pollution Control Act.[3] The Act was substantially reorganized in 1972, and became known as the "Clean Water Act" after the 1977 amendments.[4] The goal of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[5] The main tool set forth for achieving this goal is the National Pollutant Discharge Elimination System ("NPDES"). Under the NPDES program, point source water pollution is targeted and reduced.

The CWA states that "the discharge of any pollutant by any person shall be unlawful."[6] The "discharge of a pollutant" is deemed to mean "any addition of any pollutant to navigable waters from any point source."[7] The term "pollutant" includes, but is not limited to dirt, heat, biological materials, chemical waste and agricultural waste.[8]

Despite the broad prohibition on discharges of any pollutant by any person, the provision must be read in conjunction with the NPDES section of the Act. The NPDES section states that permits may be issued "for the discharge of any pollutant."[9] This section only applies, however, to point source discharges. A "point source" is defined as "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock,

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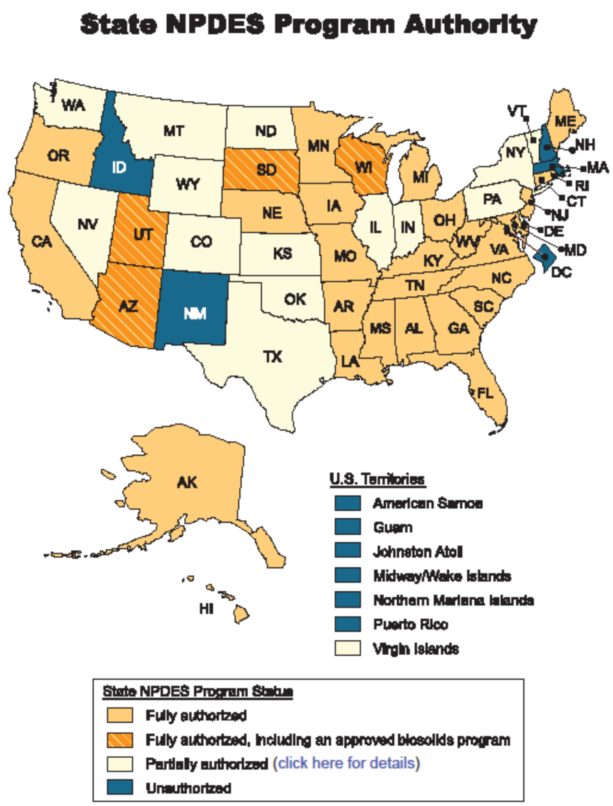
[3] U.S. Environmental Protection Agency, *Summary of the Clean Water Act*, available at: http://www.epa.gov/lawsregs/laws/cwa.html, last viewed May 12, 2011.
[4] *Id.*
[5] 33 U.S.C. § 1251(a).
[6] 33 U.S.C. § 1311.
[7] 33 U.S.C. § 1362(12). The term "navigable waters" is defined in the CWA to mean "waters of the United States, including territorial seas." 33 U.S.C. § 1362(7). The term "waters of the United States" has evolved over time, but it suffices to say for this paper that "waters of the United States" generally means waters that traditionally were navigable in fact, or susceptible to navigation, plus waters that are hydraulically connected to such waters. Rapanos v. United States, 457 US 715, 730-731 (2006); Idaho Rural Council v. Bosma, 143 F.Supp.2d 1169 (Dist. Idaho 2001). The EPA has interpreted "waters of the United States" to include "intrastate lakes, rivers, streams (including intermittent streams) … the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce," and "tributaries of [those] waters." 40 C.F.R. § 122.2(c), (e).
[8] 33 U.S.C. § 1362(6).
[9] 33 U.S.C. § 1342(a)(1).

concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged."[10]

Therefore, under the NPDES program, those who discharge "pollutants" into waters of the U.S. must obtain permits from the appropriate permit-issuing agency, which will either be the United States Environmental Protection Agency ("EPA") or a state agency authorized to administer the CWA.



Cooperative Federalism. The CWA was promulgated by the United States Congress. Congress can pass laws effecting states, but cannot "commandeer" the states to run federal programs.[11] Therefore, the CWA gives states the opportunity to establish water quality standards and to develop their own NPDES programs, but the EPA will administer the CWA within the states if the states fail to do so.[12]

Today, most states are fully authorized, meaning they have set their own water quality standards, have developed NPDES programs for issuing discharge permits (including general permits), may regulate federal facilities, and are approved to monitor pretreatment at wastewater facilities.[13]
Enforcement of the CWA. Under the CWA, the Administrator of the EPA is authorized to enforce the mandates of the CWA by criminal, civil or administrative means.[14]

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[10] 33 U.S.C. § 1362(14). Agricultural runoff is exempt from the permitting requirements of the CWA, even if collected in a ditch or pipe before being released into waters of the United States, because they are expressly removed from the definition of "discharge." 33 U.S.C. § 1362(14); 33 U.S.C. § 1342(a)(1); 40 C.F.R. § 122.3(f).

[11] AT&T Corp. v. Iowa Utilities Board, 525 US 366, 411 (1999) ("[T]he Federal Government may not commandeer state executive agencies.").

[12] 33 U.S.C. § 1319(a)(2).

[13] Partially authorized states include Washington, Nevada, Montana, Wyoming, Colorado, North Dakota, Kansas, Oklahoma, Texas, Illinois, Indiana, Pennsylvania, New York and Vermont. "Partially authorized" means that the state is approved to run certain programs, but not others. The states that are unauthorized are Idaho, New Mexico, New Hampshire, Massachusetts and Washington D.C. The EPA runs the CWA's programs in unauthorized states.

Authorized states must adopt provisions which meet the relevant requirements of the CWA, and thus are similar to the Federal provisions of the CWA.[15] For the purpose of clarity, this section will only address Federal enforcement provisions.

The Administrator is authorized to bring a criminal action, civil suit or issue an administrative order to address a violation of the CWA. Criminal penalties under the CWA are based on the type of violation involved, and listed below.

Type of Violation	Fine	Imprisonment
Negligent Violation – the violator knew or reasonably should have known	1st Conviction: $2,500-25,000 per day, per violation Past Conviction: not more than $50,000 per day, per violation	1st Conviction: 1 year or less Past Conviction: 2 years or less * Violators may be fined and imprisoned.
Knowing Violation – the violator acted with purpose	1st Conviction: $5,000-50,000 per day, per violation Past Conviction: not more than $100,000 per day, per violation	1st Conviction: 3 years or less Past Conviction: 6 years or less * Violators may be fined and imprisoned.
Knowing Endangerment – the violator knowingly violates while knowing that he is placing another in imminent danger of death or serious bodily injury	Individual: not more than $250,000 Organization: not more than $1,000,000 Past Conviction: fine doubled	1st Conviction: 15 years or less Past Conviction: 30 years or less * Violators may be fined and imprisoned.
False Statements – knowing false statement on any application, record, report, plan or other document filed or required to be maintained	1st Conviction: not more than $10,000 Past Conviction: not more than $20,000 per day of violation	1st Conviction: 2 years or less Past Conviction: 4 years or less * Violators may be fined and imprisoned.

The Administrator may also issue administrative orders to violators. The order may impose fines of not more than $10,000 per violation with a maximum fine of $25,000 for Class I violations, and not more than $10,000 per day per violation with a maximum fine of $125,000 for Class II violations.[16] The Administrator will look at aggravating and mitigating factors to determine the appropriate administrative fine.[17]

Because the consequences of non-compliance with the CWA are so severe, it is incredibly important that all dischargers comply. But how is a discharger able to comply when they are not aware of whether the CWA is applicable in their situation? This has been the problem plaguing pesticides applicators recently. The law in this area has been in flux, and the requirements for compliance have been difficult to decipher and attain.

"Pollutant"… under the Clean Water Act. The CWA prohibits the discharge of any pollutant from a point source into waters of the United States without an NPDES permit.

(Continued)

[14] 33 U.S.C. § 1319.
[15] *See, e.g.*, 33 U.S.C. § 1342(c)(3) (stating that the EPA can revoke state authorization if the state's programs or administration of the programs do not fulfill the CWA's mandates).
[16] 33 U.S.C. § 1319(g).
[17] 33 U.S.C. § 1319(g)(3).

A discharge has been held to mean an addition; the pollutant must be introduced into the water from the outside world.[18] Thus, the point source must introduce the pollutant to the waters in order to constitute a "discharge."

But what is a "pollutant"? The CWA has defined "pollutant" to mean "dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water."[19] Unlike the definition of "point source," which provides a nonexclusive list, the definition for "pollutant" provides an all-inclusive list of what constitutes a pollutant. Therefore, in order to be categorized as a pollutant for the purposes of the CWA, a material must fit within one of the aforementioned categories. However, courts have traditionally interpreted the categories broadly to include items not expressly listed.[20]

Pesticides, such as insecticides and herbicides, may be applied near, above or directly to water in order to control pests and noxious weeds. However, it is not always clear whether such substances come within the CWA's definition of "pollutant." If such substances do fit within the definition of pollutant, they must do so under the guise of "chemical wastes" or "biological materials."

<u>"Discharge" excludes agricultural irrigation return flows</u>. The CWA prohibits the discharge of pollutants into waters of the United States without an NPDES permit.[21] "Discharge" means "any addition of any pollutant to navigable waters from any **point source**."[22]

Congress has expressly excluded agricultural runoff or return flows from the definition of "point source." The CWA states: "This term [point source] does not include agricultural stormwater discharges and return flows from irrigated agriculture."[23] In addition, agricultural return flows from irrigated agriculture are exempt from the NPDES permitting process.[24]
Therefore, it is important to keep in mind that the discussion in this paper relating to the permitting of pesticide applications does not apply to pesticides in agricultural stormwater discharges and return flows from irrigated agriculture.

<u>Regulation of Pesticides under the Clean Water Act, Pre-2006</u>

By the beginning of the Twenty-First Century, it was evident that courts were split about whether pesticides constituted "pollutants." Thus, would-be-permittees did not know

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[18] Catskill Mountains Chapter of Trout Unlimited, Inc. v. City of New York, 273 F.3d 481, 489-490 (2006) (citing National Wildlife Federation v. Gorsuch, 693 F.2d 156, 165 (1982) and National Wildlife Federation v. Consumers Power Co., 862 F.2d 580 (1988)).
[19] 33 U.S.C. § 1362(6).
[20] *Rapanos*, 547 US at 724.
[21] 33 U.S.C. § 1311.
[22] 33 U.S.C. § 1362(12)(emphasis added).
[23] 33 U.S.C. § 1362(14).
[24] 33 U.S.C. § 1342(l)(1); 40 C.F.R. § 122.3(f).

whether to obtain permits before spraying, and state agencies did not know whether to bring enforcement actions for unpermitted spraying. In the Ninth Circuit alone, the court issued somewhat contradictory rulings about whether pesticides application constitutes a "discharge of a pollutant" under the CWA.[25] These rulings are discussed below.

In *Headwaters, Inc. v. Talent Irrigation District*, an irrigation district was sued after it applied an aquatic herbicide to its canals without first obtaining an NPDES permit.[26] The herbicide was released from the canals, causing fish kills.[27] The irrigation district argued no permit was necessary because the herbicide's label, which was approved under the Federal Insecticide, Fungicide, and Rodenticide Act ("FIFRA"), did not require an permit.[28] The court held that FIFRA and the CWA serve two different purposes, and that approval under FIFRA is not sufficient for compliance with the CWA.[29] Moreover, the court found that a pollutant was discharged because the pesticide residue left in the water constituted a "chemical waste" under the CWA.[30]

Similarly, in *League of Wilderness Defenders et al. v. Forsgren*, environmental groups brought suit against the United States Forest Service ("USFS") challenging aerial pesticides spraying in a national forest without an NPDES permit, conducted to curb a projected outbreak of the Douglas Fir Tussock Moth, which kills Douglas Fir trees.[31] Once again, the Ninth Circuit held that the pesticide was a pollutant, and that the USFS was required to obtain an NPDES permit before conducting spraying because the activity took place directly above streams, and thus the pesticide was discharged into those waters, even though that was not the intent of the USFS.

After the *Headwaters* and *Forsgren* decisions, California, Nevada, Washington and Oregon issued NPDES permits for pesticides applied near or to waters.[32] Other states continued traditional practices of not requiring NPDES permits for pesticide applications directly to, or over waters. The Second Circuit, recognizing this discrepancy, stated: "Until the EPA articulates a clear interpretation of current law – among other things, whether properly used pesticides released into or over waters of the United States can trigger the requirement for NPDES permits *** – the question of whether properly used pesticides can become pollutants that violate the CWA will remain open."[33]

In 2003, the EPA issued an Interim Statement and Guidance ("Interim Statement"), which stated EPA's position regarding pesticide application and NPDES permitting

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[25] The Ninth Circuit includes the states Washington, Oregon, California, Arizona, Nevada, Idaho and Montana.
[26] Headwaters, Inc. v. Talent Irrigation District, 243 F.3d 526 (9th Circuit 2001).
[27]
[28] *Id*. at 530.
[29] *Id*. at 531-32.
[30] *Id*. at 532-33. The court found that the irrigation canals were "waters of the United States" because the canals exchanged water with natural lakes and streams which themselves constituted "waters of the United States." *Id*. at 533.
[31] League of Wilderness Defenders et al. v. Forsgren, 309 F.3d 1181 (9th Circuit 2002).
[32] 71 Fed. Reg. 227 at 68485 (November 27, 2006).
[33] Altman v. Town of Amherst, 47 Fed.Appx. 62, 67 (2002).

requirements.[34] The Interim Statement espoused EPA's position that application of pesticides in accordance with all relevant requirements of FIFRA does not constitute the "discharge of a pollutant" for which an NPDES permit is required under the CWA in two situations:

1) The pesticides are applied directly to waters of the U.S. to control pests, such as applications to control mosquito larvae or aquatic weeds present in the waters; or

2) The pesticides are applied over waters of the U.S., resulting in a portion of the pesticides being deposited into waters of the U.S., such as when insecticides are applied by plane to a forest canopy where waters of the U.S. may be present, or when insecticides are used to control adult mosquito populations.

Based upon EPA's Interim Statement, the Ninth Circuit in *Fairhurst v. Hagener* held that the application of a chemical pesticide, which was applied to waters consistent with FIFRA to eliminate a pestilent fish species, and which left no residue and had no known unintended effect, did not constitute the "discharge of a pollutant" under the CWA.[35] The court further held that EPA's Interim Statement was a reasonable and not in conflict with the intent of Congress when passing the CWA.[36]

2006 EPA Final Rule

On November 27, 2006, the EPA published a final rule entitled *Application of Pesticides to Waters of the United States in Compliance with FIFRA* ("Final Rule") in the Federal Register.[37] The Final Rule, like the Interim Statement exempted certain applications of pesticides to water from the CWA's NPDES permitting requirements. If the application of pesticides to waters of the United States was consistent with all relevant requirements under FIFRA, then two circumstances were exempt:

1) The application of pesticides directly to the waters of the United States in order to control pests. Examples of such applications include applications to control mosquito larvae, aquatic weeds, or other pests that are present in the waters of the United States.

2) The application of pesticides to control pests that are present over waters of the United States, including near such waters, where a portion of the pesticides will unavoidably be deposited to waters of the United States in order to target the pests effectively; for example, when insecticides are aerially applied to a forest canopy where waters of the United States may be present below the canopy or when

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[34] 68 Fed. Reg. 156 at 48385 (August 13, 2003).
[35] Fairhurst v. Hagener, 422 F.3d 1146 (9th Circuit 2005). "A chemical pesticide applied intentionally, in accordance with a FIFRA label, and with no residue or unintended effect is not "waste" and thus not a "pollutant" for the purposes of the Clean Water Act." *Id*. at 1152.
[36] *Id*. at 1150.
[37] 71 Fed. Reg. 227 at 68483.

> pesticides are applied over or near water for control of adult mosquitoes or other pests.[38]

The Final Rule generally followed the exemptions outlined in the Interim Statement. The EPA clarified that pesticides applied in the above two situations were not "pollutants."[39]

The EPA made clear that compliance with FIFRA in order to be exempt under the CWA only concerned compliance related to water quality. Thus, non-compliance with FIFRA's provisions regarding wearing protective gear during application would not result in the necessity to obtain an NPDES permit.[40]

The EPA identified the following reasons for issuance of the Final Rule. First, chemical pesticides are not "chemical wastes" as found within the definition of "pollutant" because the ordinary meaning of the term "waste" is that which is "eliminated or discarded as no longer useful or required after the completion of a process."[41] EPA reasoned that chemical pesticides are not wastes because they have a useful purpose and are not discarded, but rather purposefully applied. Second, EPA reasoned that if Congress exempted chemical pesticides from the definition of "pollutant," then surely Congress could not have meant to include biological pesticides within the definition because not doing so would be illogical.[42] Therefore, EPA concluded that neither type of pesticide application should come under the CWA's permitting mandates.

The EPA further clarified that pesticides *do* constitute "pollutants" when contained in a waste stream or when they remain in the waters as residue after their intended purposes are fulfilled.[43] However, the EPA still exempted these pesticides from regulation under the CWA because, the EPA concluded, at the point that pesticides are in a waste stream or constitute residue, they are not being "discharged" from a "point source." Rather, they become a "pollutant" at a later time than the "discharge."[44] The EPA determined that the CWA requires that all elements of pollution be satisfied at the same time to come within the statute's requirements.

National Cotton Council of America v. US EPA

After the issuance of EPA's Final Rule, environmental groups and industry groups brought challenges, claiming that the Final Rule exceeded EPA's authority to interpret the CWA. The environmental groups alleged that EPA exceeded its authority by defining

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[38] *Id*. at 68485-68486.
[39] *Id*. at 68486.
[40] *Id*. "However, a labeling provision that governs application rates, active ingredient concentrations and dilution requirements, buffer zones, application locations, intended targets, times of day, temperature or other application requirements, and thus concerns the amounts, concentrations, and viability of substances that may potentially end up in waters of the United States, is related to water quality." *Id*.
[41] *Id*.
[42] *Id*. The EPA rationalized its conclusion based on the fact that at the time the CWA was passed chemical pesticides were predominant and biological pesticides were not as pervasive. *Id*.
[43] *Id*. at 68487.
[44] *Id*.

what constitutes a "pollutant." Specfically, these groups complained about EPA's position that residues are not discharged from a "point source," and the exemption of FIFRA-compliant applications of pesticides in general.[45] The industry groups thought that the EPA's Final Rule was arbitrary in that it treated pesticides applied in compliance with FIFRA as non-pollutants, but pesticides not applied in compliance with FIFRA as pollutants.[46] Both groups demanded judicial review of EPA's Final Rule.

Petitions for judicial review were filed in all federal circuit courts except for the Eleventh Circuit. All petitions were consolidated and heard by the Sixth Circuit in the case *National Cotton Council of America et al. v. United States Environmental Protection Agency* ("*National Cotton*").[47] In 2009, the court determined that the EPA's Final Rule was contrary to the CWA, and thus vacated the rule for the reasons discussed below.

First, the court concluded that pesticides, in general, are included within the plain definitions of the terms "chemical waste" and "biological materials."[48] Chemical wastes and biological materials are "pollutants" by definition under the CWA.[49] More specifically, the court held that there are two easily identifiable circumstances in which chemical pesticides fall within the definition of "chemical waste":

1) When chemical pesticides are intentionally applied to land or air, but excess or residual pesticides eventually end up in waterways; and

2) When chemical pesticides are intentionally applied to waterways, but excess or residue pesticides remain in the water once the pesticide's intended purpose has been completed.[50]

Additionally, the court held that all biological pesticides fall within the definition of "pollutant" because they are all "biological materials," and Congress did not limit the category by stating that only "biological wastes" qualify as "pollutants."[51]
In response to the court's findings, the EPA argued, consistent with its Final Rule, that even if certain pesticides qualify as "pollutants" under the CWA, excess and residual pesticides are not discharged by a "point source" because they only become excess or residue once they have already been applied to the waters.[52] Thus, the EPA argued that the pesticide must be applied in excess or constitute residue at the time of the application in order to come within the definition of "discharge of a pollutant from a point source."

The court rejected this argument, refusing to add a temporal requirement to the CWA which would require that the addition of the pollutant occur at the same time as the

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[45] National Cotton Council of America, et al. v. United States Environmental Protection Agency, 553 F.3d 927, 934 (2009).
[46] *Id*.
[47] *Id*.
[48] *Id*. at 935-36.
[49] *See* footnote 19, *supra*, and accompanying text.
[50] *National Cotton*, 553 F.3d at 936-37.
[51] *Id*. at 937-38.
[52] *Id*. at 938-39.

discharge.[53] The court determined that the more relevant inquiry is whether, but for the application of the pesticide, the pesticide residue and excess pesticide would have been added to the water in the first place.[54] The court concluded that since the residue and/or excess would not exist but for the initial application, that satisfied the requirement of "discharge from a point source."

Finally, the court vacated the EPA's final rule. The environmental groups' petitions were granted in part, and the industry groups' petitions were wholly denied.[55] On June 8, 2009, the Sixth Circuit granted the EPA a two-year stay of the court's ruling (until April 9, 2011) to allow agencies to prepare for NPDES permitting.[56] On March 28, 2011, the court granted a prolonged stay until October 31, 2011.[57] Under this order, applicators will not be required to obtain NPDES permits until after that time, thus exempting pesticide applications conducted in the 2011 irrigation season.

Direct Implications of the *National Cotton* Case

National Cotton vacated the EPA's Final Rule based on the court's holding that chemical pesticide wastes (excesses and residues) and all biological pesticides are "pollutants" under the CWA. Thus, the court held that applications of chemical pesticide wastes and biological pesticides to waters of the United States require NPDES permitting, or else constitute illegal discharges under the CWA.

Specifically, the holding in *National Cotton* only applies to **chemical pesticide wastes** and **biological pesticides**. It does not apply to chemical pesticides in general. Therefore, it follows that a chemical pesticide, applied to waters of the United States for a particular purpose that leaves no residue once its purpose is fulfilled, does not constitute a "pollutant" under the CWA. Applicators of chemical pesticides without waste are not obligated to obtain NPDES permits. However, in practice this distinction may be difficult to decipher, and applicators may be well-served to obtain permits to avoid CWA enforcement actions and steep administrative, civil or criminal fines and other penalties.

The EPA estimates that the *National Cotton* decision will affect "approximately 365,000 pesticide applicators nationwide that perform 5.6 million pesticide applications annually."[58] Therefore, significant planning is necessary by the EPA, authorized states, and pesticide applicators to comply with the CWA.

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[53] *Id*. at 939.
[54] *Id*. at 940.
[55] *Id*.
[56] US EPA, *Pesticides*, available at: http://cfpub.epa.gov/npdes/home.cfm?program_id=410, last viewed May 11, 2011.
[57] *Id*.
[58] US EPA, *Background Information on EPA's Pesticide General Permit*, available at: http://cfpub.epa.gov/npdes/home.cfm?program_id=414, last viewed May 11, 2011.

Farmers and Irrigation Districts are especially anxious about the additional regulatory burden.[59] It is estimated that in California farmers already pay as much as $400 per acre in regulatory costs to produce their crops.[60] Their bills will likely rise due to the additional costs associated with NPDES permitting.

The Western States Water Council ("WSWC"), which is an organization consisting of representatives appointed by the governors of the eighteen western states and provides water issues advice, has voiced its position in opposition to the *National Cotton* decision.[61] The WSWC argues that the court did not consider FIFRA's water quality protections or relationship with the CWA, and thus erroneously determined that additional permitting under the CWA was required.[62] WSWC believes that the ruling creates a duplicative and unnecessary layer of regulation without providing additional benefits, and that the burden will land most heavily on authorized states because no additional federal funding will be made available to assist states with compliance.[63]

Despite opposition, the EPA and authorized states have begun to prepare for the issuance of NPDES permits which allow pesticide applications to, and above waters. Currently, the EPA and authorized states are developing "general permits" which cover a wide range of pesticide applications. Applicators who are not covered by the "general permits" must seek individual permits from the appropriate permit-issuing agency.
On June 2, 2010, the **EPA** released its draft NPDES general permit ("Pesticides General Permit"). The draft final Pesticides General Permit was released on April 1, 2011. The permit addresses all biological pesticides, and chemical pesticides that leave a residue.[64] The permit covers operators who apply pesticides that result in discharges from certain "use patterns," including "(1) mosquito and other flying insect pest control; (2) weed and algae control; (3) animal pest control; and (4) forest canopy pest control."[65] The EPA specifies that the Pesticide General Permit will not cover spray drift or discharges into waters that are impaired for the particular pesticide.[66] The general permit also requires that operators minimize discharges, meet certain equipment standards, keep records and report, and utilize integrated pest management strategies.[67]

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[59] Cline, Harry, *Proposed NPDES permit due soon* (Western Farm Press, April 17, 2010); Cline, Harry, *More burdensome water regulations around corner for California farmers* (Western Farm Press, January 1, 2011).
[60] Cline, Harry, *More burdensome water regulations around corner for California farmers* (Western Farm Press, January 1, 2011).
[61] Western States Water Council, *Position of the Western States Water Council regarding Pesticide Applications and National Pollutant Discharge Elimination System Discharge Permits* (December 14, 2010), available at: http://www.cdphe.state.co.us/wq/PermitsUnit/PUBLICNOTICE/Pesticidesdraftinfo/328PesticideApplications10Dec14.PDF, last viewed May 20, 2011. Note that Oregon and Washington did not support the Position. *Id*.
[62] *Id*.
[63] *Id*.
[64] *Id*.
[65] US EPA, *Pesticides*, available at: http://cfpub.epa.gov/npdes/home.cfm?program_id=410, last viewed May 11, 2011.
[66] *Id*.
[67] *Id*. A full copy of the EPA's draft final Pesticides General Permit is available on the EPA's website.

California adopted three pesticide discharge permits on March 1, 2011, covering aquatic animal invasive species control, spray applications, and vector control.[68] California has had a weed control permit in place since 2004 (modified June 7, 2006).[69] The permits are each very specific as to which pesticides are covered, and they list equipment standards, record keeping and reporting requirements, and other conditions.[70] The California State Water Resources Control Board identifies that the fees associated with the permits includes a one-time fee of $136 for the Vector Control Permit, and an annual fee of $1452 for the other permits.

The **Oregon** Department of Environmental Quality has developed two general permits in response to *National Cotton*: the Pesticide General Permit, and the Irrigation District General Permit.[71] Like California's permits, Oregon's general permits are very specific as to which substances are covered, and they list application, quantity and records keeping and reporting requirements. The Oregon Department of Environmental Quality charges $437 for a new permit application fee and an annual fee of $448.[72]

Washington's general permits cover aquatic invasive species management, aquatic plant and algae management, irrigation systems, mosquito control, and noxious weed control.[73] The individual permits include fish management, invasive moth control, and an oyster growers' permit.[74] The fees associated with these permits are listed in the Washington Administrative Code, Section 173-224-040 based on the type of permit. Generally, permittees are charged an annual fee of $415 for 2011. Washington has an online permit application process for pesticide applications.[75]

The **Colorado** Water Quality Control Division ("WQCD") released a draft general permit which mirrored the EPA's general permit on January 20, 2011.[76] On April 15, 2011, the WQCD announced that it plans to have a general permit in place by October 31, 2011, and that it is currently reviewing comments and making changes in line with

[68] California State Water Resources Control Board, *National Pollutant Discharge Elimination System (NPDES)*, available at: http://www.waterboards.ca.gov/water_issues/programs/npdes/aquatic.shtml, last viewed May 12, 2011.
[69] *Id*.
[70] Full copies of each permit are available on the State Water Resources Control Board's website, listed above.
[71] Oregon Department of Environmental Quality, *Pesticide Applications to Surface Waters*, available at: http://www.deq.state.or.us/wq/wqpermit/pesticides.htm, last viewed May 12, 2011.
[72] OAR § 340-45-0075(2) (stating that general permit fees are listed in Table 70G under the "other" category); *see also* Table 70G, available at: http://arcweb.sos.state.or.us/rules/OARs_300/OAR_340/_340_tables/340-045-0075_8-27-10.pdf, last viewed May 12, 2011.
[73] Full copies of the permits are available on the Department of Ecology's Water Quality website, available at: http://www.ecy.wa.gov/programs/wq/pesticides/index.html, last viewed May 12, 2011.
[74] *Id*.
[75] Washington Department of Environmental Quality, available at: http://www.ecy.wa.gov/programs/wq/pesticides/apply_online.html, last viewed May 12, 2011.
[76] Colorado Water Quality Control Division, *Update: April 15, 2011*, available at: http://www.cdphe.state.co.us/wq/PermitsUnit/PUBLICNOTICE/Pesticidesdraftinfo/Pesticideinfoapr152011.pdf, last viewed May 20, 2011.

changes the EPA has made to its general permit since it was originally released.[77] Currently, there are about 7,500 discharge permits issued in the state, and WQCD estimates that the *National Cotton* case will increase demand by 2,000 new permits.[78] Colorado projects that this increase will require additional administrative support which will be funded through permit fees.[79] Colorado will need to amend its statutory authority to effectuate the new permit and fee program.[80]

Arizona is taking a similar approach to Colorado, and is creating a pesticide general permit mirroring the EPA's permit.[81] Arizona's draft permit divides fee categories based on the area of discharge.[82] "Single source discharges," which affect only one receiving water body, require an initial $250 fee and a $250 annual fee.[83] "Area wide discharges," which affect multiple water bodies, have fees double that for single source discharges.[84]

The **Nevada** Division of Environmental Protection, Bureau of Water Pollution Control has already developed a General Pesticide Permit (NVG870001).[85] The applicable fees are a $200 initial permit fee and a $200 annual permit fee.[86] Pursuant to the permit, operators engaged in certain pesticide activities (mosquito and other flying insect pest control, weed and algae control, nuisance animal control, and forest canopy pest control) are automatically covered by the permit for 180 days, at which time the operators must apply electronically for coverage.[87]

Certain states, such as **Idaho** and **New Mexico**, are not authorized to administer the CWA. In those states, applicators will need to look to the EPA for permits.[88]

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77 *Id*. Colorado has listed the changes that have been made to EPA's general permit since the time of its release at: http://www.cdphe.state.co.us/wq/PermitsUnit/PUBLICNOTICE/Pesticidesdraftinfo/COG860000FS.pdf, last viewed May 20, 2011.

78 Colorado Water Quality Control Division, *Proposed General Permits for Discharges from the Application of Pesticides in Colorado*, available at: http://www.cdphe.state.co.us/wq/PermitsUnit/PUBLICNOTICE/Pesticidesdraftinfo/Pesticideinfo.pdf, last viewed May 20, 2011.

79 *Id*.

80 *Id*. A list of current discharge fees may be viewed at: http://www.cdphe.state.co.us/wq/PermitsUnit/POLICYGUIDANCEFACTSHEETS/factsheets/Fees.pdf, last viewed May 20, 2011.

81 Arizona Department of Environmental Quality, Water Quality Division, *Arizona Pollutant Discharge Elimination System (AZPDES)*, available at: http://www.azdeq.gov/environ/water/permits/azpdes.html, last viewed May 20, 2011.

82 *See* Arizona's draft permit, available at: http://www.azdeq.gov/environ/water/permits/download/draft_pgp.pdf, last viewed May 20, 2011.

83 *Id*.

84 *Id*.

85 Nevada Department of Environmental Protection, Bureau of Water Pollution Control, *General Information: Federal Pesticide Applications Permitting Program*, available at: http://ndep.nv.gov/bwpc/pesticide.htm#NVG870001, last viewed May 20, 2011.

86 *Id*.

87 Nevada General Pesticide Permit, available at: http://ndep.nv.gov/docs_11/nvg870001_permit2011.pdf, last viewed May 20, 2011.

88 More information about pesticide permitting under the CWA in other western states may be found as follows: **Texas**: http://www.tceq.texas.gov/agency/permitting/water_quality/stakeholders/pesticidegp_stakeholder_group.html; **Utah**: http://www.waterquality.utah.gov/PublicNotices/PGP_Final_300.pdf; **Montana**: http://deq.mt.gov/wqinfo/mpdes/ pesticides.mcpx; **Oklahoma**: http://www.deq.state.ok.us/wqdnew/401_404/index.htm; **South Dakota**: http://denr.sd.gov/des/sw/PesticidePermit.aspx.

The EPA's NPDES Permits

Pesticides General Permit. A general permit covers multiple persons or facilities that may be grouped due to similarities.[89] Once a group is identified, a draft permit is issued, followed by public notice, a public comment period, and the issuance of the final permit.[90] Facilities or persons wishing to be covered by a general permit typically must submit a Notice of Intent to the permitting agency for inclusion under the permit.[91] The EPA's Pesticides General Permit is a five-year permit that licenses the discharge of pesticides falling within four "use patterns" as explained above. The permit does not cover terrestrial pesticide applications, rather only certain aerial and aquatic pesticide applications which result in unavoidable discharges into waters of the U.S.[92] Eligibility for coverage under the general permit is based upon fitting within the specified "use patterns." However, an applicator otherwise applying pesticides consistent with an identified use pattern will not be covered if the discharge is made into waters that are already impaired by a pesticide or its degradates, or waters designated as Tier 3 waters, which are outstanding waters that may not be degraded under the CWA.[93]

Whether an operator (a person with control over the financials or who applies the pesticides) must submit a Notice of Intent ("NOI") depends on whether the operator knows or should know that they will exceed annual treatment area thresholds, which are described in the general permit. If not, they are automatically covered by the general permit. Operators can submit an NOI via internet, and the EPA reviews NOIs to verify the operator does not need an individual permit. Operators required to submit NOIs must use Integrated Pest Management Practices, create and submit a Pesticide Discharge Management Plan, and submit annual reports to the EPA.[94]

All operators must meet technology-based effluent limitations, including minimizing pesticide discharges, using the lowest effective amount of the pesticide, and performing regular maintenance and inspection of equipment. Operators must also conduct site monitoring, report adverse incidents to EPA, and keep certain records.[95]

Individual Permits. If a permit is required, but a discharge is not covered by the general permit, the applicator will need to obtain an individual permit. The applicant must submit an application to the EPA, who will first review it for completeness and accuracy. Then, the permit writer will tailor a permit specifically for the applicant, including developing technology-based effluent limitations and water-quality based effluent limitations

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[89] US EPA, *Water Permitting 101*, available at: http://www.epa.gov/npdes/pubs/101pape.pdf, last viewed August 30, 2011.
[90] *Id.*
[91] *Id.*
[92] US EPA, *Pesticides General Permit (PGP) for Point Source Discharges to Waters of the United States from the Application of Pesticides (Draft)*, available at: http://www.epa.gov/npdes/pubs/proposed_pgp.pdf, last viewed August 31, 2011.
[93] *Id.*
[94] *Id.*
[95] *Id.*

(choosing the more stringent limit), creating special and standard conditions and considering variances.[96] Like general permits, once a draft permit is completed, public notice is given to allow for public comments prior to issuance of the final permit.[97] Individual permits are effective for a specified amount of time, not to exceed five years.[98]

Cross-Over Implications of the *National Cotton* Case

Pesticides are controlled under a wide array of statutes and regulations. As already mentioned, FIFRA governs the registering, labeling, use and sale of pesticides in the United States.[99] The Endangered Species Act ("ESA") requires that federal agencies consult to ensure that actions do not jeopardize listed species, and also prohibits the "taking" (killing or harming) of listed species.[100] The National Environmental Policy Act ("NEPA") requires federal agencies to conduct formalized decision-making to evaluate the environmental impacts of actions.[101] States have adopted programs mirroring these federal programs. All of these statutory and regulatory schemes require the coordination of numerous federal agencies, including the EPA the Department of Agriculture, the Fish and Wildlife Service and more, and numerous state agencies across the nation.

Although not the topic of this paper, it is important to recognize the sheer magnitude of regulations facing pesticide applicators. On January 18, 2011, President Barack Obama signed an executive order entitled "Improving Regulation and Regulatory Review."[102] In his address, the President recognized that many federal regulations are outdated, not accomplishing their intended goals while standing in the way of economic development. President Obama thus called for a house-cleaning of overly burdensome regulations. While any benefits that may accrue from this executive order are still forthcoming, one wonders if the overlapping pesticide regulations will be a target of the initiative. Pesticides are addressed by so many regulations and so many different state and federal agencies that pesticide application has become both confusing and expensive. It remains to be seen whether pesticide control will become an area for reform in the future.

CONCLUSIONS

Pesticide use is widespread for a variety of useful purposes. However, pesticides can also be quite harmful if used irresponsibly. Thus, pesticides have become the target of heavy regulation, oversight and enforcement.

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[96] US EPA, *supra* note 89.
[97] *Id.*
[98] *Id.*
[99] US EPA, *Overview of FIFRA*, available at: http://www.epa.gov/agriculture/lfra.html#Summary%20of%20the%20Federal%20Insecticide,%20Fungicide,%20and%20Rodenticide%20Act, last viewed May 12, 2011.
[100] US EPA, *Summary of the Endangered Species Act*, available at: http://www.epa.gov/lawsregs/laws/esa.html, last viewed May 12, 2011.
[101] US EPA, *National Environmental Policy Act (NEPA)*, available at: http://www.epa.gov/compliance/nepa/, last viewed May 12, 2011.
[102] Obama, Barack, *Toward a 21st-Century Regulatory System*, available at: http://online.wsj.com/article/SB10001424052748703396604576088272112103698.html, last viewed May 12, 2011.

Despite the heavy regulation, until recently it was up for debate whether the requirements of the CWA applied to pesticide applications to and above waters. In order to quell speculation, the EPA passed a Final Rule which determined that pesticides did not qualify as “pollutants” under the CWA, or otherwise were not “discharged” into waters, and thus applications did not require permitting under the CWA’s NPDES program. However, the *National Cotton* case vacated the Final Rule, holding that the CWA did indeed apply.

Currently, federal and state agencies are preparing to issue NPDES permits in compliance with the court’s holding. As a result of permitting requirements, pesticide applicators will face increased costs which will be passed onto the public. Moreover, the permitting requirements add yet another layer to the complex regulatory framework surrounding pesticide use. Pesticide regulation may be an ideal area of the law to coordinate reform and synchronization in the future.

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QUANTIFYING RESOURCE MANAGEMENT STRATEGY BENEFITS AND ROBUSTNESS

Rich Juricich[1]

ABSTRACT

This paper describes the concepts behind the application of futures scenarios as part of an analytical framework to quantify and evaluate the performance of resource management strategies for the California Water Plan. The California Water Plan, mandated by state law and updated every five years, is used to guide statewide water policy decisions. Scenarios of future regional and statewide water demand through 2050 were developed for the California Water Plan, Update 2009 by the California Department of Water Resources. Three narrative scenarios of alternative future growth were developed using a stakeholder driven process expressing three plausible themes or storylines that highlight important uncertainties surrounding future water demands. A description is provided of how the analytical framework is being updated in response to stakeholder feedback during development of Update 2013 of the Water Plan.

MANAGING AN UNCERTAIN FUTURE

California is dynamic and ever changing. And over the next decades its moving forces--population growth, a variable and changing climate, and a desire to promote water use efficiency, regional self-sufficiency, better water quality and environmental sustainability—will significantly change the management of the state's water resources. A changing climate means we can no longer rely exclusively on past rainfall and temperature records to make informed decisions about the frequency, duration, and severity of future floods and droughts or to estimate future consumptive water uses. Many future uncertainties and risks now confront decision-makers, water and resource managers, and land use planners who need to consider a range of possible future conditions.

PREPARING FOR AN UNCERTAIN FUTURE

To prepare for future challenges in managing its water resources California can make strategic investments in water conservation, water recycling, conjunctive management of surface water and groundwater storage, and desalination of brackish and sea water to name a few. Table 1 shows over two dozen resource management strategies identified in California Water Plan Update 2009 (DWR 2010) and available to most regions to help improve water management conditions. The strategies in Table 1 are grouped according to broad water management objectives like *reducing water demand*, but each strategy has the potential to provide multiple benefits. Because each region has limits to financial

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resources to implement these strategies, each must carefully evaluate strategy costs, benefits, and tradeoffs in a thoughtful and collaborative way to choose cost effective and robust strategies.

Table 1. Resource Management Strategies from California Water Plan Update 2009

Reduce Water Demand • Agricultural Water Use Efficiency • Urban Water Use Efficiency **Improve Operational Efficiency & Transfers** • Conveyance – Delta • Conveyance – Regional / Local • System Reoperation • Water Transfers **Increase Water Supply** • Conjunctive Management & Groundwater Storage • Desalination –Brackish & Seawater • Precipitation Enhancement • Recycled Municipal Water • Surface Storage – CALFED • Surface Storage – Regional / Local **Improve Flood Management** • Flood Risk Management	**Improve Water Quality** • Drinking Water Treatment & Distribution • Groundwater / Aquifer Remediation • Matching Quality to Use • Pollution Prevention • Salt & Salinity Management • Urban Runoff Management **Practice Resource Stewardship** • Agricultural Lands Stewardship • Economic Incentives (Loans, Grants & Water Pricing) • Ecosystem Restoration • Forest Management • Land Use Planning & Management • Recharge Areas Protection • Water-dependent Recreation • Watershed Management **Other**-- Crop idling, dew vaporization, fog collection, irrigated land retirement, rainfed agriculture, waterbag transport

EVALUATING WATER MANAGEMENT STRATEGIES AND SUPPORTING DECISIONS

Water managers seek strategies that are dynamic, adaptive, robust, and affordable. Strategies must be comprehensive and integrate multiple physical, environmental, and socio-economic objectives to achieve sustainable outcomes. The long term merits of alternative strategies may differ considerably depending on how the future unfolds. Water managers need better data and tools to quantitatively evaluate alternative strategies and support decision making in light of many future risks and uncertainties. To this end the Water Plan since Update 2005 (DWR 2005) has solicited advice from the Statewide Water Analysis Network[2] (SWAN) to pursue the following technical activities:

1. **Resources Strategy Performance –** Collaboratively evaluate and quantify the performance of resource management strategies against costs, benefits, and tradeoffs.
2. **Resources Strategy Robustness** - Test the robustness of potential resource management strategies under alternative future scenarios that consider the full

[2] SWAN serves as the technical advisory group for the Water Plan and is comprised of scientists and engineers from federal, state, and local agencies, consulting firms, universities, and non-governmental organizations. Additional information can be found at http://www.waterplan.water.ca.gov/swan.

spectrum of uncertainties and risks that may confront water planners in California regions.

3. **Decision Support** - Develop a collaborative process to support Integrated Regional Water Management Plans, regional decision making, and identify interregional linkages to guide sustainable water management policies.

Resources Strategy Performance

California's regions through their Integrated Regional Water Management Plans need to invest in a diverse mix of cost-effective resource management strategies that can satisfy multiple resource objectives over the long term with sustainable outcomes. Multi-objective planning often seeks to minimize total economic costs or maximize the total economic, social, and environmental benefits to a region when implementing a set of strategies. This analysis requires a detailed and dynamic representation of the water management system in order to quantify potential costs, benefits and tradeoffs of alternative strategies. Table 2 shows some of the key benefits identified in Update 2009 that could be used to evaluate the performance of resource management strategies.

Table 2. Potential Resources Strategy Benefits from California Water Plan Update 2009

Provide water supply benefit	Operational flexibility and efficiency	Energy benefits
Improve drought preparedness	Reduce flood impacts	Recreational opportunities
Improve water quality	Environmental benefits	Reduce groundwater overdraft

The Water Plan is developing methods to regionally quantify and evaluate the costs, benefits, and tradeoffs of different resource management strategies through the application of the Water Evaluation And Planning (WEAP) modeling platform[3]. WEAP is used to represent both the physical water management system and existing and potential resource management strategies. The physical water management system is represented by estimates of current and future precipitation, runoff to streams and rivers, flows into surface reservoirs, and many other components represented conceptually in Figure 1. The Water Plan, working through regional partners, will apply the WEAP modeling platform at a regional and subregional scale to quantify a subset of the benefits shown in Table 2, for a selected group of strategies from Table 1, and subject to the limitations described at the end of this paper.

[3] The WEAP model is developed and maintained by the Stockholm Environment Institute. Additional information can be found at http://www.weap21.org.

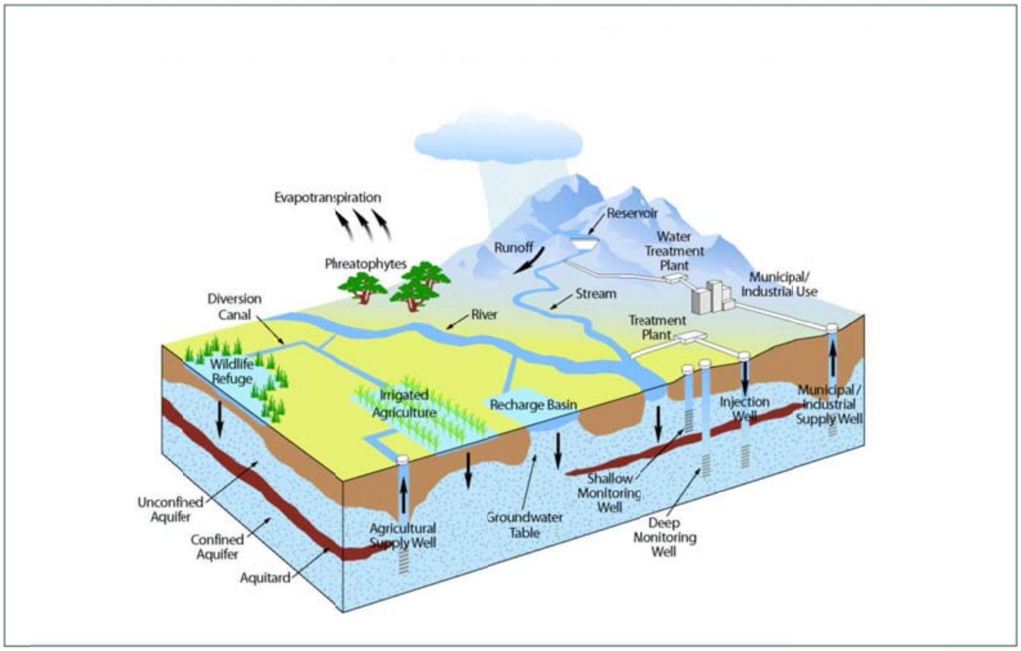

Figure 1. Conceptual water management system.

Resources Strategy Robustness

Since Update 2005, the California Water Plan has used the concept of future scenarios to capture a broad range of uncertain factors that affect water management, but over which water managers have little control. Scenarios are used to test the robustness of strategies by evaluating how well strategies perform across a wide range of possible future conditions. Robust strategies are those that perform sufficiently well in meeting water management objectives across many scenarios. Water Plan scenarios are organized around themes of population growth, land use patterns, levels of environmental protection and climate change. Growth scenarios are used to characterize a range of uncertainty surrounding future water demand. Climate scenarios explore how future climate change might influence timing, distribution, and amount of precipitation and water requirements. Figure 2 summarizes three growth scenarios—Current Trends, Slow & Strategic Growth, and Expansive Growth-- developed for Update 2009.

Key points to consider when thinking about scenarios:

- Scenarios describe alternative plausible yet very different future conditions represented in a thematic way.
- Scenarios explore key uncertainties over which the water community has little control, like future population growth, land use, levels of environmental protection and climate change.
- Scenarios are not predictions of the future, but rather different plausible future conditions used to evaluate the robustness of potential resource management strategies.

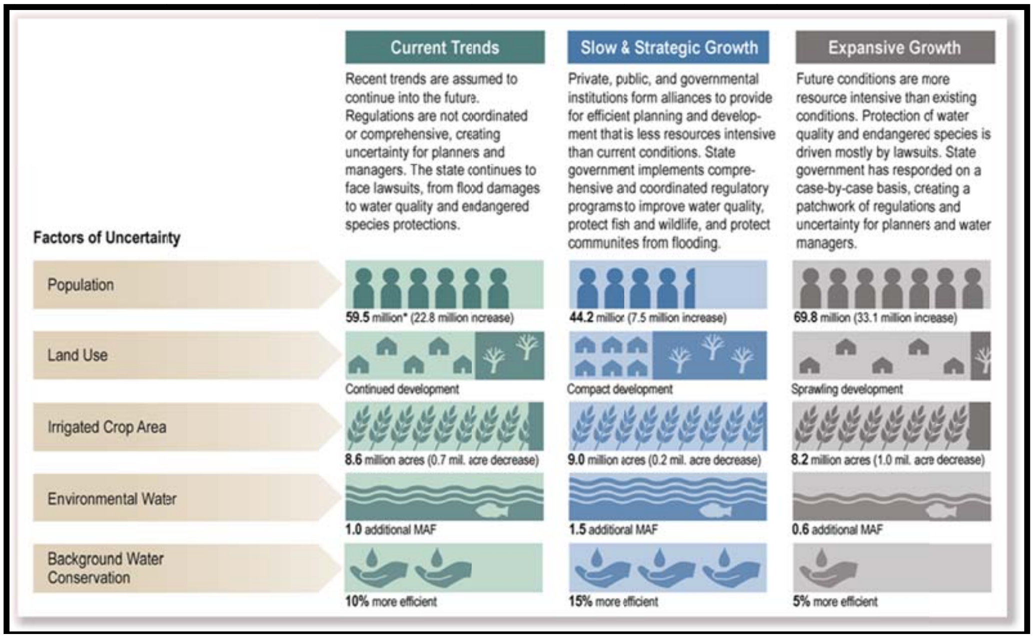

Figure 2. Water Plan Update 2009 Growth Scenarios

Decision Support

Decision-makers often take action on issues that affect water management even when there is significant uncertainty either about the basic scientific understanding of the water management system or about the political or social acceptance of particular water management alternatives. The Water Plan is working to improve analytical approaches and collaborative processes to effectively quantify where scientific uncertainties exist, help overcome political and social disagreements, and identify actions that will have more sustainable outcomes. The Water Plan is working collaboratively with regional water management groups to develop a shared understanding of the water management system, to improve upon existing data and analytical tools, and to identify the regional costs, benefits, and tradeoffs associated with implementing alternative mixes of resources management strategies.

DWR is applying Shared Vision Planning[4] techniques through the Water Plan to support decision-making and achieve the following technical goals and outcomes:

- Achieve better integration and consistency with other planning activities
- Obtain consensus on quantitative deliverables
- Build a common conceptual understanding of the water management system
- Improve transparency of Water Plan information

[4] The term *Shared Vision Planning* is most closely associated with the U.S. Army Corps of Engineers, Institute for Water Resources which has been implementing the approach and methods since the National Drought Study in the 1990s. See www.SharedVisionPlanning.us for additional information.

EVALUATING RESOURCE MANAGEMENT STRATEGIES FOR WATER PLAN UPDATE 2013

The Water Plan employs an extensive stakeholder process, which is helping to guide the definition and evaluation of resource management strategies under alternative future scenarios for Update 2013. This includes a State Agency Steering Committee comprised of state agencies that develop statewide water management policy; a public advisory committee representing both statewide interest and place-based interests; The Statewide Water Analysis Network (SWAN); a Federal Agency Network, a California tribal advisory committee, and a number of regional forms and topic based caucus groups. Content was shared through a series of workshops to consider improvements that can be made to maintain the technical soundness and policy relevance of the future scenarios described in Figure 2. Through these workshops, three key improvements were recommended:

- Evaluate how factors like climate, land use decisions, and population interact to affect future water use. Separating out land use effects from other factors is difficult to do under the Update 2009 scenarios because many factors are combined under each scenario shown in Figure 2. For example under the Slow and Strategic Growth Scenario, it is hard to distinguish the effects a slower population growth rate and more compact development patterns on the overall change in water demand estimates shown in Figure 3.
- Remove background water conservation and providing additional water to the environment as scenario factors. These factors should be included as resource management strategies that can be evaluated along with many other strategies identified in Update 2009. The Water Plan is able to evaluate how many strategies perform under many different plausible future conditions.
- Make use of improved analytical tools developed for the Water Plan to perform a more comprehensive evaluation of resource management strategies in light of many future risks and uncertainties. These improvements allow quantification of strategy costs, benefits, tradeoffs, and vulnerabilities.

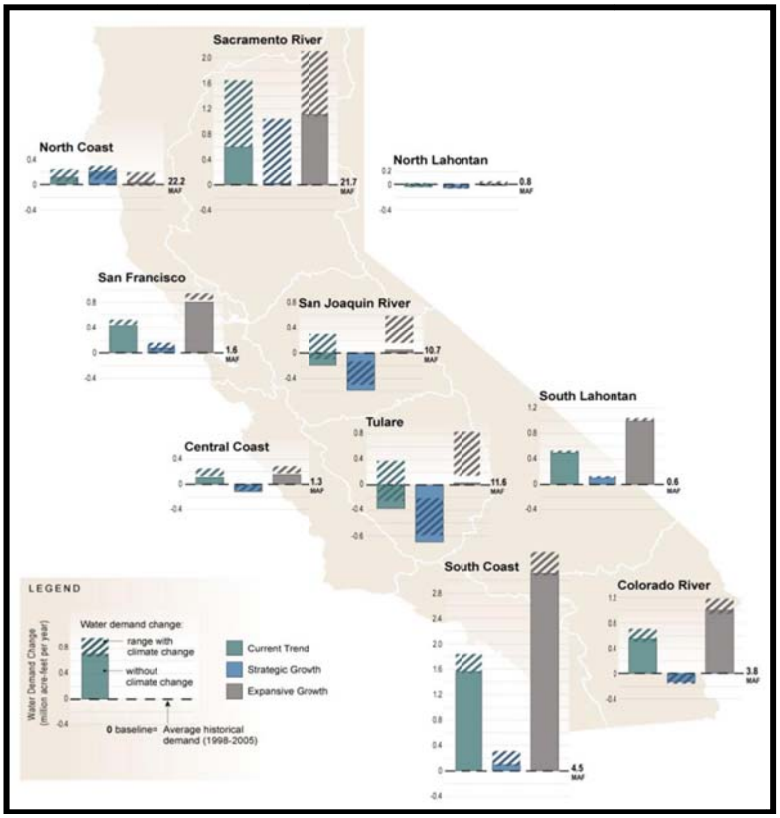

Figure 3. Future Regional Water Demand Changes by Scenario from Update 2009

LIMITATIONS

The WEAP modeling platform under development by the Water Plan can allow comprehensive analysis of regional resource management strategy performance when conducted at sufficient detail. However, all technical endeavors are subject to the limits of the particular technology being used and the financial resources available. Below are some of the important limitations the Water Plan has identified for the analysis proposed for Update 2013.

- Update 2013 will perform the comprehensive analysis described in this paper for the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions (See Figure 3). The analysis for the remaining 7 hydrologic regions in California will be coarser and will focus on quantifying future water demands under alternative future scenarios similar to the analysis performed for Update 2009.
- Many of the resource management strategies identified in Table 1 can be represented in the Water Plan application of WEAP, particularly those grouped under the water management objectives *reduce water demand*, *improve operational efficiency and transfers*, and *increase water supply*. However, the proposed analysis for Update 2013 will have limited ability to quantify strategies grouped under the objectives

improve flood management, *improve water quality*, and *practice resource stewardship*.

- The analysis proposed for Update 2013 will quantify some of the resource management strategy benefits shown in Table 2 related to *providing a supply benefit, improving drought preparedness, environmental benefits, operational flexibility and efficiency, and reducing groundwater overdraft*. There will be limited ability to quantify other benefits related to *improving water quality, reducing flood impacts, energy benefits,* and *recreational opportunities*; however, these may be described qualitatively.
- The conceptual water management system in Figure 1 captures many of the hydrologic and water management components that can be represented in WEAP. The WEAP model developed to support the Water Plan is designed to represent the water management system at sufficient detail to reflect important *regional* planning conditions, but not for local operations or to capture all detailed flows through the system. As a result, many system features, such as groundwater basins, are simplified to capture the broad regional behavior of groundwater recharge, groundwater storage and hydrologic connection to rivers and lakes.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the efforts of the staff and consultant team that have transformed the conceptual ideas expressed in this paper into the analytical framework being implemented through the California Water Plan. This includes Dr. Mohammad Rayej with the California Department of Water Resources, Dr. Andy Draper with MWH, Dr. David Purkey and Dr. Brian Joyce with the Stockholm Environment Institute, Dr. David Groves and Evan Bloom with RAND Corporation, and Dr. David Yates with the National Center for Atmospheric Research. Their collective wisdom has provided tremendous insight and credibility to this work.

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EVALUATING CPC LONG RANGE PRECIPITATION FORECASTS IN THE NORTHERN SIERRA NEVADA

Maurice Roos[1]

ABSTRACT

The Climate Prediction Center (CPC) of the National Weather Service (NWS) has been making long range weather forecasts for over two decades with 0.5 to 12.5 months of lead time. If the forecasts of 1 to 6 months ahead are reliable, they would help water project operators in providing earlier estimates of water yield which would be available during the coming season with some increase in yield in some years. In this paper I have reviewed 11 years of monthly precipitation forecasts for the northern Sierra Nevada region of California, testing how actual precipitation compared with that forecasted. Some skill is indicated, mostly in El Nino years, but quite limited. Gradual improvements over the years may, in time, make these forecasts another tool for water project managers, especially in early season water supply forecasts. The bulk of this paper is a discussion of various tests of forecasted and observed precipitation for the monthly, 1 to 3 month and the 4 to 6 month projections.

BACKGROUND

The northern Sierra Nevada is the most important runoff region in California, furnishing much of the water for the two largest water projects in the state—the federal Central Valley Project (CVP) and the State Water Project (SWP)—as well as most of the water for the Sacramento-San Joaquin River Delta. Estimated precipitation accumulation during the water year is monitored using eight stations to represent the 15,700 square mile watershed of the four major rivers. of the region. The first figure map shows the locations of the eight stations, which range from Mount Shasta City in the north to Pacific House in the south. During the fall and winter and beyond, accumulated precipitation at the eight stations can provide an early estimate of water supply for the coming year. There is nearly 90 years of record for the eight station index.

The Climate Prediction Center has been making long range weather forecasts of temperature and precipitation since the late 1980s with a lead time of 0.5 to 12.5 months. The temperature forecasts have shown more skill than the precipitation ones. But reliable precipitation forecasts are of more value for the water user. For water operators, the forecasts with the greatest potential are those for the winter season. On average, half the annual precipitation in northern California, whether rain or snow, occurs during the December through February period, with three-fourths from November through March. (See the pie chart in the second figure.) Reliable forecasts during the early part of the rainy season have the most value as many decisions on water delivery and crop planting are made at that time before the halfway point in the rainfall accumulation season.

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Shortly after the first of February, the Department of Water Resources adds the snowpack measurements to the runoff forecasting methodology and the reliability improves.

Figure 1. Location of Northern Sierra 8 Stations.

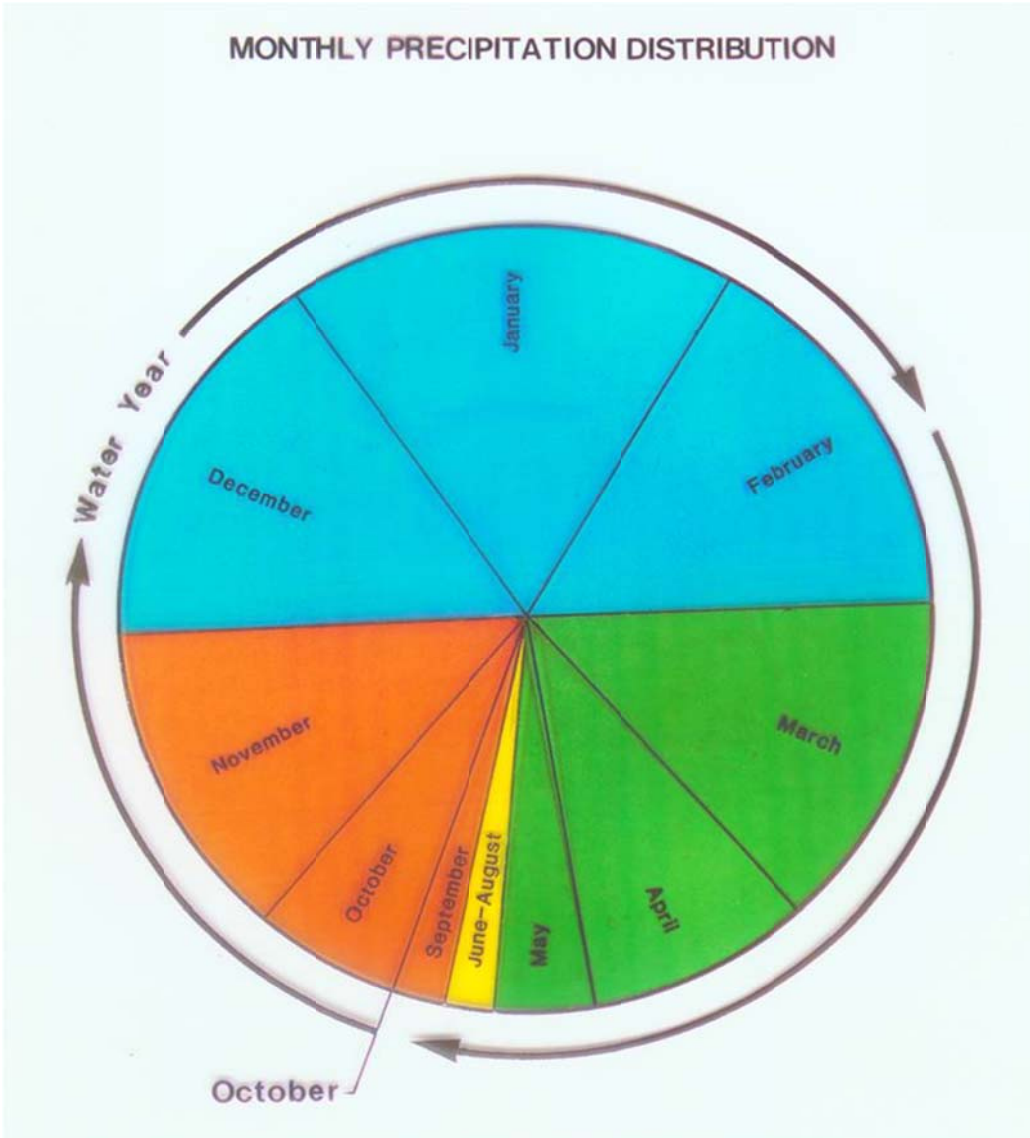


Figure 2. Month Distribution of Northern California Preciptation.

The CPC precipitation forecasts use 3 categories: more than chance probability of being wetter than median, drier, and no slant either way (shown as equal chances). Once in a while they indicate a zone where the probability is such that the area will be near normal. Usually only small portions of the country will be marked as more likely to be wet or dry with the larger space on the map being without a signal. Figure 3 is a sample of a precipitation forecast map showing how the information is presented. Most of the time a precipitation shift is fairly modest. The edges of the shaded area are 33 percent and increase to 40 or 45 percent and rarely 50 percent chance of being in the wet or dry tercile (third) category.

EVALUATION

We tested the forecasts with the northern Sierra eight station record of monthly or 3 month period precipitation for 11 calendar years from 2000 through 2010. We looked at the 0.5 month lead for the one month outlook, the 1 - 3 month outlook, and the 4 - 6 month outlook, which is labeled as the 3.5 month 3 month outlook by the CPC. To do this we reviewed all the forecasts, noting which ones showed all or part of the northern Sierra watershed region in one of the shaded forecast areas. We made a judgment on the strength of the shift away from normal. These ranged from a slight 1 percent to a shift of 9 percent. To test the skill we then checked whether the measured precipitation was more or less than median for the month or the 3 month period. The skill is when the actual precipitation was in the same direction as the forecast. If it went the opposite way, the forecast was wrong. For example, if the forecast was shaded toward a wetter condition, a hit would be when the actual precipitation was above median—the right direction. About half the forecasts for the region showed EC, equal chances, that is no signal. The EC forecasts were not counted when computing the skill.

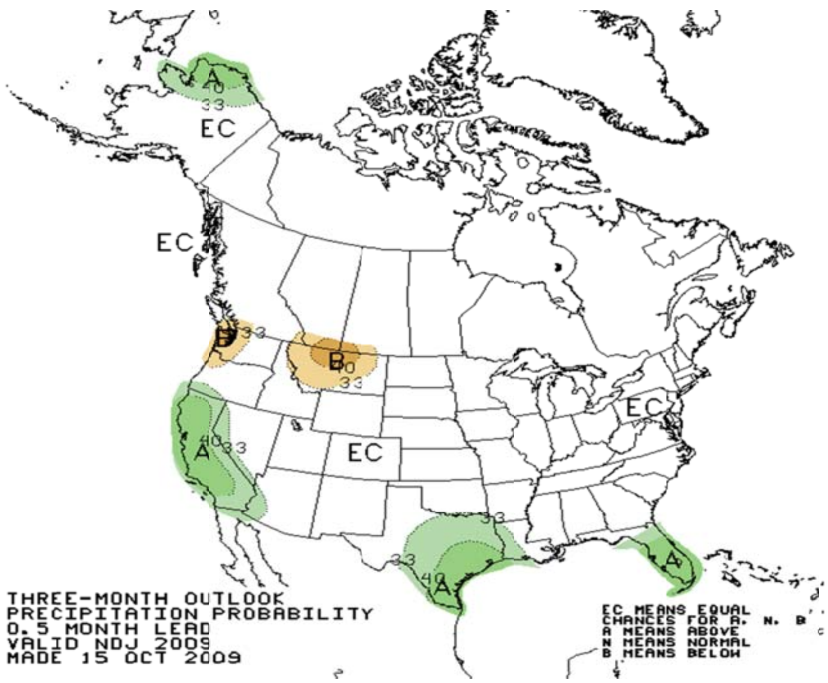


Figure 3. Sample CPC Precipitation Forecast Map

Results are shown on the first table for the 2000-2010 period of 11 years. They show some skill: the 0.5 one month forecast Heidke skill was 23 percent, that is 23 percent better than chance, the 1 – 3 month skill was 25 percent, and the 4 – 6 month skill was a surprising 19 percent. However, when we looked at just the 5 wet months, for November through March (Table 2), the skill fell apart for the one month outlook with 0 skill, and decreased to 18 percent in the 1 – 3 month forecasts. Puzzlingly the 4 – 6 month skill went up to 75 percent, but the sample size was small at only 8. The conclusion is that the forecasts are better in the drier months which don't matter as much for water supply.

Table 1. CPC Forecast Evaluation Northern Sierra
11 Years: 2000-2010

	Number With Signal	**Right Direction**	**Wrong Direction**	**Approx Skill**
1 Month	**52 32 20**			**0.23**
1-3 Months	**67 42 25**			**0.25**
4-6 Months	**42 25 17**			**0.19**

Table 2. CPC Forecast Evaluation Northern Sierra
11 Years: 2000-2010, Nov-Mar

	Number with Signal	**Right Direction**	**Wrong Direction**	**Approx Skill**
1 Month	**20**	**10**	**10**	**0**
1-3 Months	**22**	**13**	**9**	**0.18**
4-6 Months	**8**	**7**	**1**	**0.75**

Another evaluation was to examine just the months where a stronger confidence of wetter or drier conditions was indicated using a 5 percent shift as a threshold. The sample size was small. This did not show any consistent skill; in fact, the computed skills were all negative on Table 3.

Table 3. CPC Forecast Evaluation Northern Sierra
11 Years: 2000-2010, Strong Signal

	Number with Signal	**Right Direction**	**Wrong Direction**	**Approx Skill**
1 Month	**11**	**4**	**7**	**-0.27**
1-3 Months	**19**	**5**	**14**	**-0.47**
4-6 Months	**20**	**5**	**15**	**-0.50**

Note: A strong signal is one with a 5 percent or more shift.

Another way to look at forecast results is to see how often the actual precipitation fell in the upper or lower tercile and to use how often their direction, either wet or dry, was correctly indicated in the forecasts. Skill would be shown if the actual precipitation during those calls were slightly higher than the 33 percent expected from chance. Again no skill was shown, except some in the 4 – 6 month outlook (see Table 4).

Table 4. CPC Forecast Evaluation Northern Sierra
11 Years: 2000-2010, Correct Third

	Number with Signal	Correct Tercile	Approx Skill
1 Month	**53**	**10**	**-0.30**
1-3 Months	**70**	**17**	**-0.27**
4-6 Months	**41 16 0.17**		

In 2004, the CPC started revising the 1 month forecast at the end of the month. This did help quite a bit with the skill for that period rising from 23 percent for the 0.5 month period to 52 percent for the end of month revised outlook. A major factor is that forecasters can look at end of month weather patterns then in making their call and so improvement would be expected.

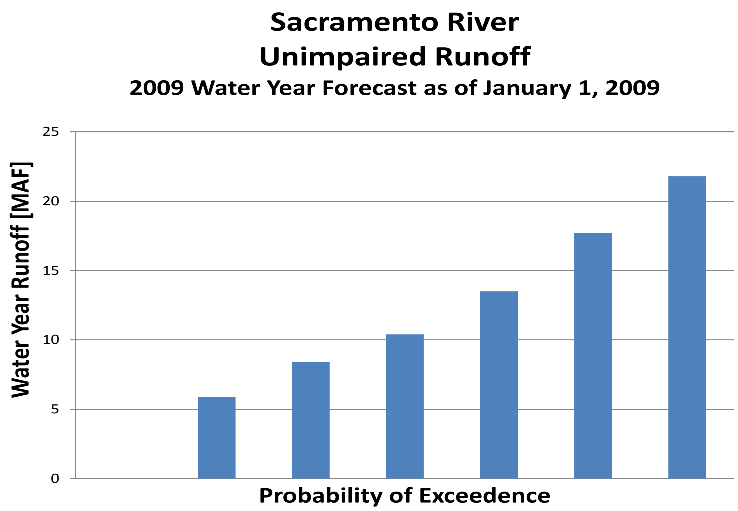
The last table, Table 5, shows the directional skill each year of the 11 years for each of the three forecasts evaluated. The best years were 2006, 2008, and perhaps 2010. There is a suggestion of improvement with time over the 11 years. But results in intervening 2007 year were poor, more wrong than right.

Table 5. CPC Directional Skill By Year
Northern Sierra Precipitation

Year	One Month			1-3 Months			4-6 Months		
	EC	**Right**	**Wrong**	**EC**	**Right**	**Wrong**	**EC**	**Right**	**Wrong**
2000	4	4	4	7	2	3	6	4	2
2001	7	3	2	9	2	1	10	1	1
2002	7	3	2	4	5	3	8	2	2
2003	8	2	2	4	6	2	9	1	2
2004	7	4	1	6	4	+1 med 1	10	1	1
2005	9	1	2	6	3	3	9	2	1
2006	8	4	0	8	3	1	6	4	2
2007	9	1	2	4	3	5	7	2	3
2008	7	4	1	7	4	1	9	3	0
2009	9	2	1	3	5	4	8	2	2
2010	4	4	+1 med 3	6	5	1	8	3	1
Total	79	32	20	64	42	25	90	25	17

USE OF THE FORECAST

For early season water project operations, the owner agencies are quite conservative. They are always worried that the season could turn dry and they would be unable to deliver amounts promised earlier in the season. Therefore initial estimates of delivery are based on water in storage in the reservoirs and the amount of runoff anticipated for dry future conditions, either at the 90 or 99 percent probability level. Figure 4 shows an example for 2009, during our recent 3 year drought, of the January 1st Sacramento River runoff forecast and how it changed during the month of December. Project operators (and the bankers who make crop loans to farmers) want to be very sure the water is there before promising delivery. For the SWP, that means the first allocation, usually shortly after December 1, is often less than a 50 percent supply. In water year 2009, it was only 10 percent, which eventually was raised to 40 percent in this 3rd year of drought. In addition to the promised allocation, estimates of water delivery to users to be expected with normal future weather conditions (50-50 chance) and 75 and 25 percent probabilities are provided to guide water users in planning for the ensuing year. Because of the emphasis on dependability, a potentially important forecast product would be for forecasters to be able, with high confidence, to rule out future dry conditions in the forecast period, a more difficult task.



Date of Forecast	99%	90%	75%	50%	25%	10%
1-Dec-08	5.1 (27%)	8.2 (44%)	10.8 (58%)	14.8 (79%)	19.9 (107%)	24.8 (10%)
1-Jan-09	**5.9 (32%)**	**8.4 (45%)**	**10.4 (56%)**	**13.5 (73%)**	**17.7 (95%)**	**21.8 (117%)**

Figure 4. Forecasts of WY 2009 Sacramento River System Runoff

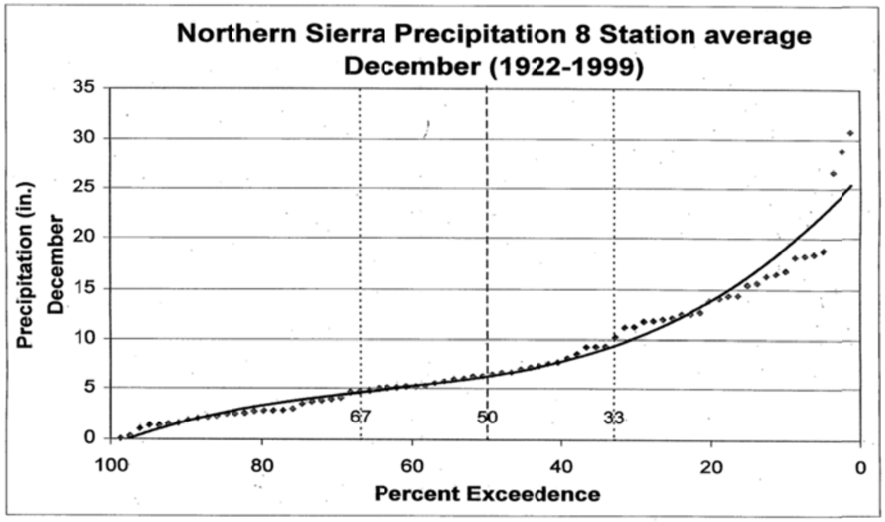


Figure 5. Probability of December Monthly Precipitation.

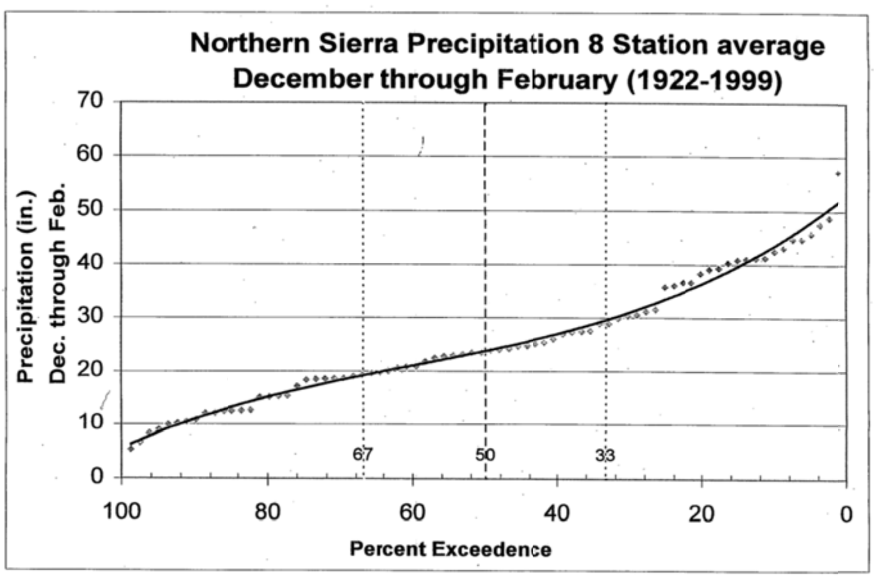


Figure 6. Probability of Winter Season Precipitation.

Probability shifts in the future precipitation can be worked into a runoff forecast. But, so far, the shifts are small—on the order of 5 percent. Near median probabilities, a 5 percent shift translates into fairly small quantitative amounts. See Figures 5 and 6 for the range of one month December and the 3 month December through February winter season historical probabilities for precipitation amounts. For example, a 5 percent shift near median conditions works out to only about 1 ½ inches in the 3 month winter season precipitation. As long as the climatological dry end of the spectrum is possible, these small shifts don't really change a seasonal runoff forecast much. Reliability, especially in precluding future dry conditions, will have to improve a lot before significant changes in water operations are likely. There is a better chance to make use of small shifts in outlook if an agency has a good backup supply, such as groundwater, to take up the slack if the forecast is wrong. Some of the water customers do have multiple sources of water supply and are able to use the probability products to guide their operational planning.

CONCLUSION

Some of the CPC long range skill in the past is due to strong El Nino-Southern Oscillation (ENSO) signal years, particularly bigger El Ninos. Except for a moderate one in 2010, there were no strong El Ninos in this 11 year period. We were coming out of a strong cold La Nina event in year 2000 , with cold events in 2008 and the end of 2010, but La Nina events don't seem to have much signaling power in northern California. Results so far with the long range forecasts have not been that useful for water supply forecasting. But we need to keep trying and to monitor how well such forecasts do.

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WEST-WIDE CLIMATE RISK ASSESSMENTS: BIAS-CORRECTED AND SPATIALLY DOWNSCALED SURFACE WATER PROJECTIONS

Subhrendu Gangopadhyay, PhD, PE[1]

ABSTRACT

Public Law 111-11, Subtitle F (SECURE Water Act), section (§) 9503 authorizes the U.S. Department of Interior's Bureau of Reclamation (Reclamation) to assess climate change risks for water and environmental resources in "major Reclamation river basins." Section 9503 also includes the authorities to evaluate potential climate change impacts on water resource management and development of strategies to either mitigate or adapt to impacts. This paper provides an overview of the analysis that was conducted as part of the West-Wide Climate Risk Assessments (WWCRA) in the eight major Reclamation river basins including the Colorado, Columbia, Klamath, Missouri, Rio Grande, Sacramento, San Joaquin and Truckee. The analysis included translating bias corrected and spatially downscaled (BCSD) climate projections to hydrologic projections for these eight basins and characterizing hydroclimate impacts in terms of changes in runoff volumes and timing, and changes to precipitation, temperature and snowpack (measured using snow water equivalent or SWE) for three look ahead decades, 2020s, 2050s and 2070s from the 1990s. Overall it was found that precipitation distribution varies across basins, but temperature shows a persistent increasing trend, decrease in April 1st SWE, an increasing trend in winter season runoff, and decreasing trend in spring-summer season runoff. Also, all the data used in the analysis is being made available through a web service at the Lawrence Livermore National Laboratory's Green Data Oasis facility.

INTRODUCTION

Public Law 111-11, Subtitle F (SECURE Water Act), section (§) 9503 authorizes the U.S. Department of Interior's Bureau of Reclamation (Reclamation) to assess climate change risks for water and environmental resources in "major Reclamation river basins." Section 9503 also includes the authorities to evaluate potential climate change impacts on water resource management and development of strategies to either mitigate or adapt to impacts. The major Reclamation river basins listed within the SECURE Water Act are the Colorado and Columbia River Basins and the Klamath, Missouri, Rio Grande, Sacramento, San Joaquin, and Truckee River basins. Reclamation is accomplishing the SECURE Water Act authorities through activities within its WaterSMART Basin Study Program.

The analysis is focused on changes in hydroclimate variables—namely, precipitation, temperature, snow water equivalent, and streamflow across the major Reclamation river basins. The analysis involves developing hydrologic projections associated with World Climate Research Programme Coupled Model Intercomparison Project3 (WCRP CMIP3) climate projections that have been bias-corrected and spatially downscaled and served at the following Web site: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections. In

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total, 112 hydrologic projections were developed, relying on watershed applications of the Variable Infiltration Capacity (VIC) macroscale hydrology model (Liang et al. 1994). From these time-series climate and hydrologic projections (or hydroclimate projections), changes in hydroclimate variables were computed for three future decades: 2020s (water years 2020–2029), 2050s (water years 2050–2059) and 2070 (water years 2070–2079) from the reference 1990s' decade (water years 1990–1999). The reference 1990s are from the ensemble of simulated historical hydroclimates, and not from the observed 1990s.

DATA AND MODELING

Gridded (1/8 degree [°] by [x] 1/8°, latitude by longitude) VIC applications covering the major Reclamation basins and the Western United States were obtained through a collaborative effort with personnel from University of Washington, and National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Colorado Basin River Forecast Center. These VIC applications are described at the University of Washington Westwide Streamflow Forecasting System, formerly featured at http://www.hydro.washington.edu/forecast/westwide/ and documented in Wood and Lettenmaier 2006, Wood et al. 2005, and also Maurer et al. 2002. Before performing climate change simulation runs, these VIC applications were used to simulate historical streamflow at a menu of locations across the Western United States. This included a total of 43 West-Wide Climate Risk Assessment (WWCRA) sites and 152 Hydroclimate Data Network (HCDN) sites spanning the major Reclamation river basins and the Western United States. A subset of these locations was used to compare VIC simulated historical flows with observed natural or unimpaired flows to characterize the VIC simulation biases (difference between observed and simulated streamflow magnitudes). The VIC applications largely were applied "as-is," i.e., without any additional efforts to improve upon their existing level of calibration.

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind magnitude as input to simulate gridded daily state variables such as snow water equivalent and runoff (both surface and subsurface runoff). These gridded runoffs are then hydraulically routed to the menu of locations. To develop the hydrologic projections, the Bias Correction and Spatial Disaggregation (BCSD) archive of gridded (1/8° x 1/8°, latitude by longitude) monthly total precipitation and average temperature for each of the 112 projections temporally was disaggregated to develop daily time-series of precipitation and maximum and minimum temperatures.

Use of the climate projections in this assessment involved several important choices, specifically: (1) the choice of BCSD climate projections; (2) retaining all the 112 BCSD climate projections; and (3) choosing to do a time-evolving analysis rather than a step-change climate analysis.

RESULTS AND DISCUSSIONS

Example results and discussions for the Sacramento-San Joaquin River Basins abstracted from the Reclamation technical memorandum (Reclamation 2011) is presented in this section.

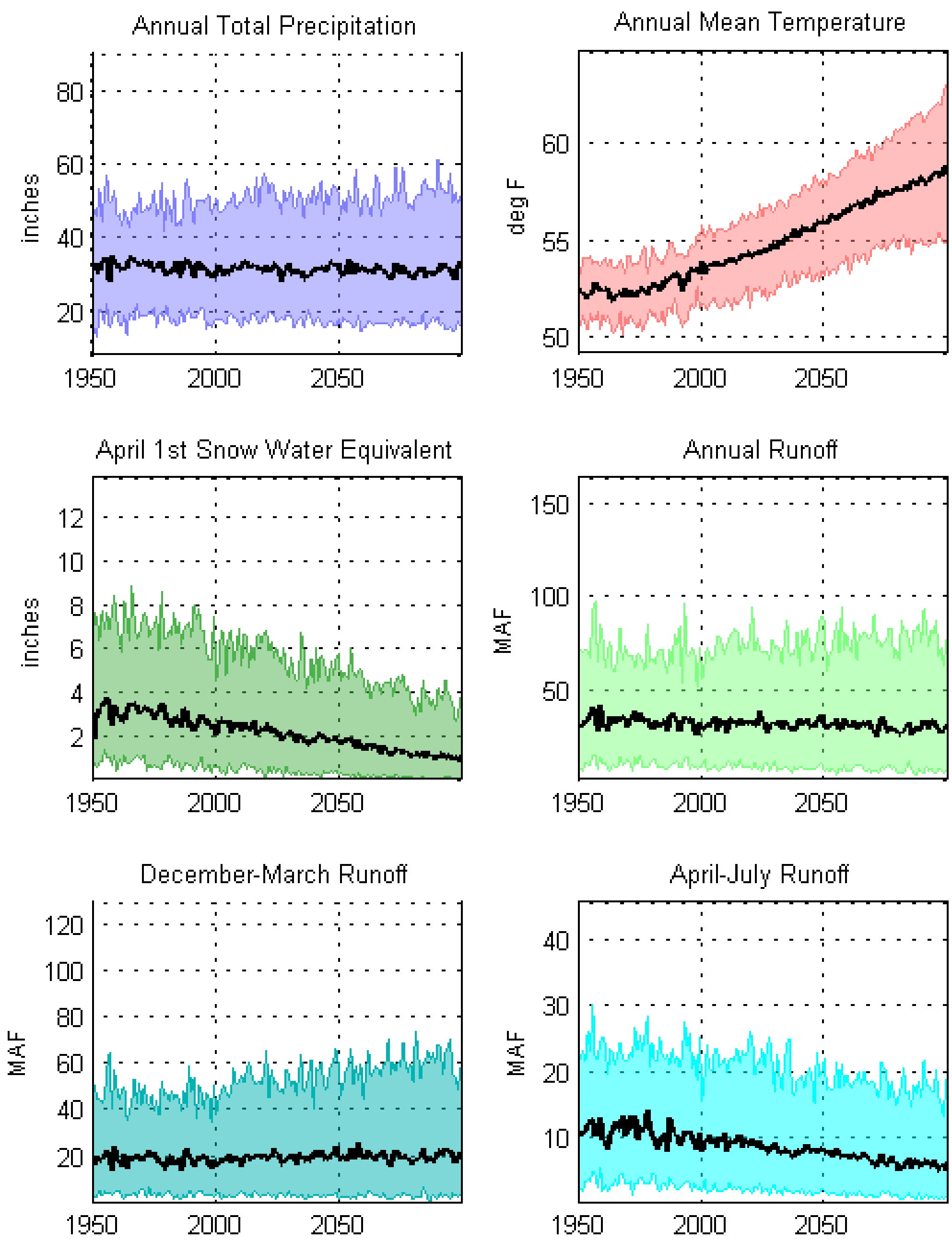

Figure 1. Sacramento and San Joaquin Basins – Hydroclimate Projections.

Figure 1 shows six ensembles of hydroclimate projections for the basin above the Sacramento and San Joaquin Rivers at the Delta: annual total precipitation (top left), annual mean temperature (top right), April 1st SWE (middle left), annual runoff (middle right), December–March runoff season (bottom left), and April–July runoff season (bottom right). The heavy black line is the annual time series of 50 percentile values (i.e., ensemble-median). The shaded area is the annual time series of 5th to 95th percentile.

Annual total precipitation shows a decreasing trend. Annual mean temperature shows an increasing trend. April 1st SWE shows a decreasing trend. Annual runoff shows only a nominally decreasing trend. Winter season runoff shows a nominal increasing trend, and the April–July runoff shows decreasing trend.

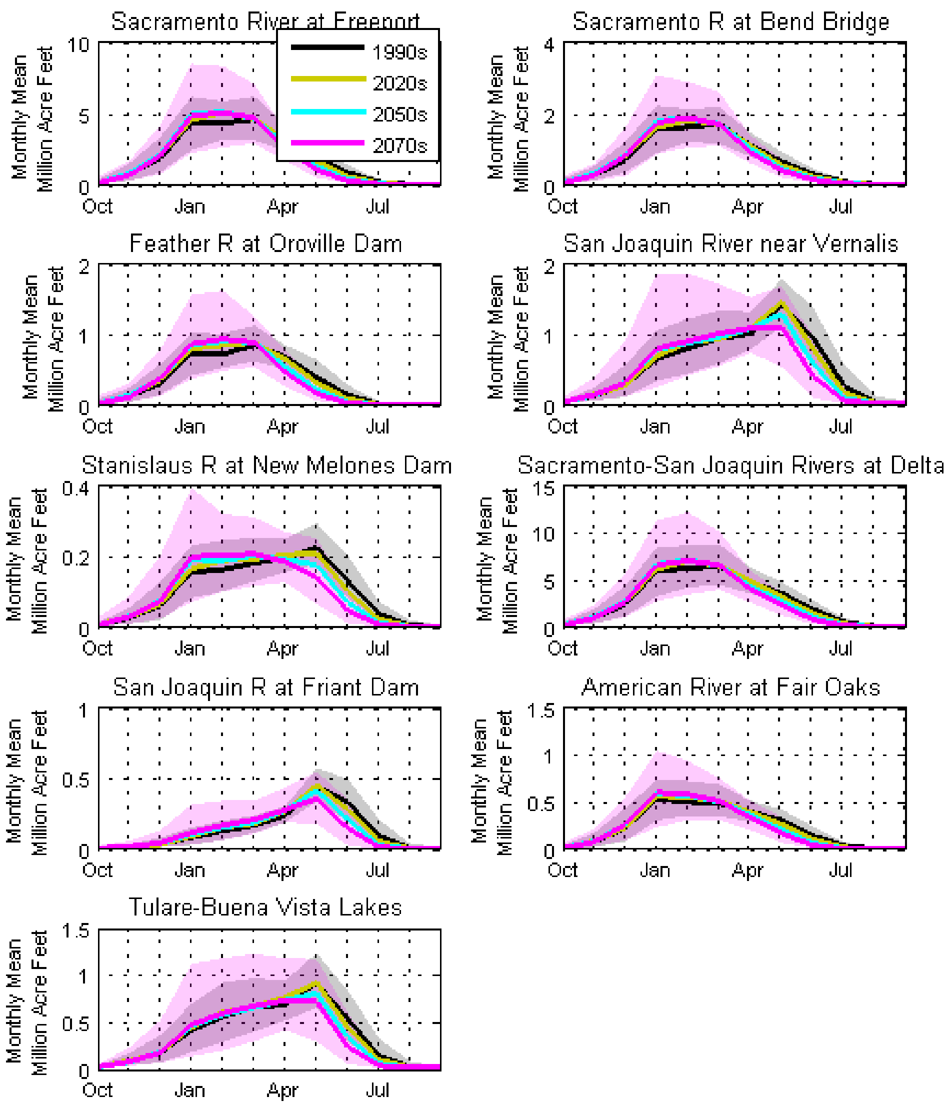

Figure 2. Sacramento and San Joaquin Basins — Simulated Mean-Monthly Runoff for Various Subbasins.

Figure 2 shows ensemble-median mean-monthly values (heavy lines) for the 1990s, 2020s, 2050s, and 2070s and the decadal-spread of mean-monthly runoff for the 1990s (black shaded area) and 2070s (magenta shaded area) where spread is bound by the ensemble's 5th to 95th percentile values for each month. For all the locations, there appears to be an earlier shift in the peak runoff timing; and for some locations, for example the Stanislaus River at New Melones Dam and the San Joaquin River near Vernalis, there is significant earlier shift to the peak runoff timing.

SUMMARY AND CONCLUSIONS

A total of 43 subbasins were analyzed for the WWCRA effort. These locations largely correspond to major sites used in Reclamations decision models. The impacts across the 43 subbasins vary, but there appears to be emerging patterns that, in summary, are the following.

(1) Precipitation is expected to increase from the 1990s' level during the 2020s and 2050s but to decline nominally during the 2070s (though the early to middle 21st century, increases could be artifacts of the BCSD climate projections development leading to slightly wetter projections, as discussed in section 3.4 of Reclamation 2011).

(2) Temperature shows a persistent increasing trend from the 1990s' level.

(3) April 1st SWE shows a persistent decreasing trend from the 1990s' level.

(4) Annual runoff shows some increase for the 2020s' decade from the 1990s' level but shows decline moving forward to the 2050s' and 2070s' decade from the 1990s' reference, suggesting that, although precipitation changes are projected to remain positive through the 2050s, temperature changes begin to offset these precipitation increases leading to net loss in the water balance through increased evapotranspiration losses.

(5) Winter season (December–March) runoff shows an increasing trend.

(6) Spring–summer season (April–July) runoff shows a decreasing trend.

This analysis was designed to provide quantitative representation of how runoff in the major Reclamation river basins may respond to a range of future climate projections. The activity was designed to take advantage of best available datasets and modeling tools and to follow methodologies documented in peer-reviewed literature. However, there are a number of analytical uncertainties that are not reflected in study results, including uncertainties associated with the climate projection information and methods used in assessing hydrologic impacts.

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