Upgrading Technology and Infrastructure in a Finance-Challenged Economy

A USCID Water Management Conference

Sacramento, California
March 23-26, 2010

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

Edited by

Bryan P. Thoreson
Davids Engineering, Inc.

Susan S. Anderson
U.S. Committee on Irrigation and Drainage

Published by

U.S. Committee on Irrigation and Drainage
1616 Seventeenth Street, #483
Denver, CO 80202
Telephone: 303-628-5430
Fax: 303-628-5431
E-mail: stephens@uscid.org
Internet: www.uscid.org

USCID

The Mission of the United States Committee on Irrigation and Drainage is to foster sustainable, socially acceptable and environmentally responsible irrigation, drainage and flood control systems and practices for providing food, clothing and shelter to the people of the United States and the World.

USCID is a nonprofit professional society whose members share an interest in the planning, design, construction, operation and maintenance of irrigation, drainage and flood control works; agricultural economics; water law; and environmental and social issues affecting irrigated agriculture.

USCID is the United States member of the **International Commission on Irrigation and Drainage** (ICID), an association of more than 70 countries. Founded in 1950, ICID is a non-governmental organization dedicated to the sound and responsible management of water resources. Its central purpose is to promote the development and application of the sciences and techniques of irrigation, drainage, flood control and river channel stabilization.

USCID publishes the *USCID Newsletter*, proceedings of USCID meetings and special reports; organizes and sponsors periodic technical meetings and Conferences; and distributes ICID publications.

Since 1986, USCID has organized a number of regional, national and international meetings throughout the U.S. These meetings address contemporary issues affecting irrigated agriculture, offering a multi-disciplinary evaluation of problems and solutions.

For additional information about USCID, its meetings, publications and membership, contact

USCID
1616 Seventeenth Street, # 483
Denver, CO 80202
U.S.A.

Telephone: 303-628-5430
Fax: 303-628-5431
E-mail: stephens@uscid.org
Internet: www.uscid.org

Printed in the United States of America

Library of Congress Control Number: 2010922643

ISBN 978-1-887903-30-1

Preface

The papers included in these Proceedings were presented during the **USCID Water Management Conference**, held March 23-26, 2010, in Sacramento, California. The Theme of the Conference was *Upgrading Technology and Infrastructure in a Finance-Challenged Economy***.** An accompanying book presents abstracts of each paper.

Financing infrastructure and technology, a challenge in normal times, has become even more difficult for irrigation water supply providers as a result of the recent tightening of the credit markets. Irrigation districts, and other water providers, face a continuing need to upgrade technology and infrastructure even in these tight credit markets that complicate financing. Response to droughts, climate change and increased scrutiny of water management practices continues to drive upgrading of irrigation infrastructure and technology.

In response to these challenges, irrigation districts are developing innovative financing and funding solutions. These include developing partnerships with other agencies, applying for grants, loans and other sources of financial assistance, along with consideration of rate increases. Some are entering into agreements to transfer water. Others are agreeing to share facilities. Some districts are utilizing wastewater for irrigation or recharge. Irrigation districts and other agencies are using these and other strategies to maintain and upgrade the services they provide in these challenging financial times.

The papers presented during the Conference technical sessions and poster session focused on these issues. Technical sessions addressed the following topics: Innovative Technologies; Urban/Ag Partnerships; Upgrading Infrastructure; Finance and Economics; Water and Energy Supply/Conservation; and Water Planning.

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

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

Bryan P. Thoreson
Davids Engineering, Inc.
Davis, California

Conference Chairman

Contents

Water Planning

Poster Session

CONCEPTS IN WATER RESOURCES ECONOMICS PAST AND FUTURE

Rick L. Gold, P.E, D.WRE.[1]

ABSTRACT

This paper discusses the basic concepts of Water Resources Economics by exploring water resource investment decisions in general. The paper lays out various views related to the need and desirability of rigorous economic evaluation and contrasts that approach with the purely political approach to securing authorization and funding. It discusses the costs of developing ideas, the more detailed project planning and design, and the ultimate decision of "to build or not to build". The litany of how those decisions have historically been made will be discussed as will the concepts of who has made them. The development of the 1983 Principles and Guidelines and the recent re-evaluation of them will be considered. The paper deals with how investment decisions are made from the perspective of what funding sources are likely available for implementation. The factors which might be considered are discussed in terms of benefits, costs, and priorities. The paper concludes with a look to the future of water resource investment decisions and a discussion of likely future scenarios that could lead to successful implementation.

WHAT ARE INVESTMENT DECISIONS?

Exploring Ideas Costs Money

Many people fail to grasp the significance and importance of water resource investment decisions. Making good decisions is seldom a matter of chance. On a personal level few would approach a decision about where to invest their money without a fair amount of evaluation of the kinds of options that were available, the potential risks and rewards of the options, and the likely outcome of making the investment. In a world where time is money, investing the time to plan can be costly but not thinking things through can be even more costly. Sound planning can make the difference between success and failure. The overall objective in project development is to arrive at the correct solution and spend the least overall cost in building that project.

In water resources investment, simply exploring the ideas costs money. Whether it is your staff or a consultant who begins with your idea and starts the process of developing and examining the options those very early phases of "thinking it through" are done by folks who earn a paycheck. The better the job that's done in sorting out the ideas the better the long term prospect for getting the idea implemented. Those initial dollars spent can pay off significantly as the process moves forward. Unfortunately many see this upfront investment as simply delaying the start of the project. For those of us who grew up being planners it is a critical investment in keeping us from going down the wrong path only to retreat and start over at some later time.

[1] Senior Consultant, CDM, 1886 South Wasatch Drive, Salt Lake City, UT 84108; goldrl@comcast.net

Investment decisions start with the early evaluation of the ideas to be implemented and a sorting of options to the point where a potentially successful project begins to materialize. Keeping this early evaluation at a general, less detailed level helps keep the costs in check. It makes no sense to spend significant amounts on detailed study of options that will be discarded later in the process.

Planning and Design

While some of the early exploration of ideas is also a part of “planning”, many associate only the development of a Feasibility Report with planning. There have been, and continue to be, lots of names for planning documents; reconnaissance studies, appraisal studies, feasibility studies, definite plan reports, special studies, etc. The real focus of planning is to sort out the alternative projects or ways of accomplishing the project to define the actual project you plan to develop. It costs lots of money and takes time but in the end the process leads to the selection of the correct plan for implementation.

The next phase is design. The design phase usually produces the specifications and detailed instructions for the construction of your project. This effort is very costly and time consuming depending on the complexity of the project. It makes sense to only spend the money to design the actual project you intend to build. The benefits of the early screening and winnowing processes help to arrive at the project to be implemented first and then design it rather than spending the money designing several alternative projects and then discarding all that design work done on a project or option that you ultimately decide not to build. While it is not possible to set clear budget targets for the magnitude of funding needed for the planning phase verses that needed for the design phase it is the author’s experience that a good planning effort might range in the $500 K to $1 M range while many design efforts can cost in the $5 M – $10 M range, depending on the complexity of the project.

This whole planning and design phase is about starting with ideas and ending up with the best possible choice of options or projects during a progressively more detailed effort. This yields a process which is efficient and effective. At the end you do detailed design of the project you intend to build and proceed with implementation.

To Build or Not To Build

Sometime during this planning and design phase is the right time to get serious about the ultimate decision of implementation. It makes little sense to decide to move forward to implement if you don’t clearly understand the project, how it will be built, where the funding will come from to construct it, or the benefits to be derived from it. It also makes little sense to spend all the time and money on planning for every contingency on the project before moving toward taking the necessary steps to assure that it can be built. Some suggest that you know you are going to implement the project from the beginning and the rest is just details. It is this tension in perspective that makes the process of water resource decision making so interesting. What tends to make the processes different is the source of the money for project implementation. If it’s yours and you are ready to go you should proceed. If that funding belongs to someone else your task is really to convince them to spend the money and build it. Particularly in the area of federal funding, as will be explored later in this paper, convincing them to spend it is a big job.

WHAT IS THE HISTORY OF WATER RESOURCES DEVELOPMENT DECISIONS?

Groups of Individuals

Many early water resources development decisions were made by groups of individuals who were spending their own money to build projects. Sometimes there were individuals or groups of investors who provided the capital. In the case of the first five Reclamation Projects (the Salt River Project in Arizona, the Newlands Project in Nevada, the Milk River Project in Montana, the North Platte Project in Wyoming, and the Gunnison Project in Colorado) authorized in 1903 each expanded on previous investments by individual users. Undoubtedly the decisions that were made to move ahead with these projects were based on some of the principles and theories of the day that suggested that a return on the investment was possible. In a few cases the decision to build a project was the only decision that would allow those early farmers to make a living in their location. When investors or groups of investors made decisions to fund the development is was likely because they believed the creation of the project, including all of the secondary benefits to be derived, was worth the price. Many of those early projects were pretty inexpensive, by today's standards, and much of the work was done by the farmers with their own labor and equipment. Some of those projects were not well funded, and the primary goal was the delivery of water rather than to have too much concern for the long term sustainability of the project. They figured out how to deliver the water to allow irrigation to be successful. In many cases, it was a "figure it out as we go" approach. This approach resulted in wide variance in the level of success.

State Support and Projects

Along the way some of these projects sought help from their states as projects needed funding to complete construction or to sustain the operation and maintenance. Some states stepped in to support the projects and undoubtedly had some significant economic decisions to make. At that point one can only guess that the decisions were about the sustainability of the area's economy in general rather than just the projects direct benefits and costs.

Eventually some of the states themselves began to consider and invest in water resources projects for the benefit of their citizens. It is the author's belief that many states likely went through some difficult decision making about whether to invest in a particular project or not. The key element in moving to this broader base of support was that the citizens of the state could tax themselves and spread the cost to all those who might receive some of the indirect benefits. In many cases, these projects were successful but in some cases the next logical step was to engage the federal government for financial support.

Federal Projects

In the late 1800s the move to set up a program within the federal government to finance water resources projects began in earnest. Many were interested and ultimately in 1902 the Reclamation Act was passed into law giving the Reclamation Service a role in planning, designing, building, and operating water resource projects in the West. It is how these decisions, made by the Federal Government, are made that is the principal focus of this paper. As we will discuss later in the paper, it is the multiple processes of planning for and authorizing the construction and operation of these Federal projects that creates the backdrop for some of the economic controversy that faces water resources development in the future.

HOW ARE FEDERAL WATER RESOURCES INVESTMENT DECISIONS MADE?

Funding a Federal Project

When the United States sets out to spend the people's money it becomes a relatively complicated process. Under the separation of powers only Congress, in the Legislative Branch, can spend (appropriate) money. The normal process for doing this, at least in water resources situations, is by Congress first passing a law **authorizing** the expenditure of money for the purpose of the project, the President of the United States, in the Executive Branch, must sign that law before it is enacted, Congress then must **appropriate** the money to an agency in the Executive Branch by passing another law (an appropriations bill), the President must also sign this law before it is enacted, then the Executive Branch Agency is allocated the money from the US Treasury according to the appropriations law and can spend it for the purposes for which it was authorized.

As one might guess this process is not quick and easy and there are many opportunities for mischief. In many instances the process from introduction of a bill authorizing a water resource project to the time the agency gets its first appropriation of funding to actually begin constructing the projects can take many, many years. For example, the Animas La Plata Project in Colorado and New Mexico was actually authorized for construction in 1968 and the first real construction funding began to flow to the project in 2002; thirty four years later! In this case the ideas for the project were first considered in the 1920s and the water rights were identified in 1938. These early years of planning all lead up to the authorization for construction contained in the Colorado River Basin Project Act of 1968. Many examples could be presented where this Federal process was arduous, tedious, debated, re-visited, litigated (in the Judicial Branch), and in a few cases succeeded. But given that this process is daunting, the Federal Government did set out some specific procedures in order to make the decisions about which projects should be supported during the process of authorization and appropriations.

Implementing More Purposeful Processes

The 1902 Reclamation Act set the federal funding process in motion by establishing the Reclamation Fund within the US Treasury. The original concept of the fund was that monies received from the sale and disposal of public lands in the western states were to be placed in a special fund to be used to examine, survey, construct, and maintain irrigation works. Once constructed, those projects were to be repaid by the recovery of the cost of construction in ten annual payments from the farmers with the money returned to the Reclamation Fund for use in developing the next Reclamation project. Obviously many of those principles have changed over the years with additional money added to the Reclamation Fund from the General Fund, repayment periods adjusted up to 40-50 years, and numerous project purposes added to the mix. It is interesting to note that little is said in the 1902 Act about the processes or principles to be used in making the investment decisions. The fundamental idea was that the project be practicable and advisable from the perspective of the Secretary of the Interior who was the decision maker.

With the enactment of the 1936 Flood Control Act as a part of Reclamation law the idea that a project purpose (in this case flood control) could be in the interest of the general welfare became part of law. This concept is likely based upon the 1920s work of Professor Arthur C. Pigou in his book "The Economics of Welfare" in which the idea that the "welfare of man" could be measured and thus that the impact of an action (like the construction of a water project) on that "welfare" could be determined. That work also recognized that some of that impact could be monetized and some could not. Monetized impacts could be measured in the dollars of wages, income, crops, etc. while non-monetized impacts like open space, scenic views, and clean air could not. Nonetheless all the impacts on the "welfare of man" were recognized and in the 1936 Flood Control Act we see the first reference to the need for benefits to exceed costs and the beginnings of the ideas for a benefit to cost ratio.

Practices, Principles, Standards, Procedures, and Guidelines

By about the 1950s, the first attempt to provide some guidance in this direction materialized. The Subcommittee on Benefits and Costs of the Federal Inter-Agency River Basin Committee produced the Green Book. The title of this book (with a green colored cover) was "Proposed Practices for Economic Analysis of River Basin Projects." When, in support of these concepts, the Bureau of the Budget, now the Office of Management and Budget (OMB), published Circular A-47 with a strict focus on making sure that benefits exceeded cost for any project, many in Congress became disenchanted with this strict test. In 1962 Senate Document 97 was published which set out a broader, compromise position. It was a multi-objective approach that provided for reasoned choices among development, preservation, and well being of people. There was no requirement for benefits to exceed costs in Senate Document 97. However it did allow for the Bureau of the Budget to adopt such a standard for the administration. History would show that this need for a B/C ratio greater than 1:1 became the rule.

The Water Resources Planning Act of 1965 established the Water Resources Council and charged that new body with the development of Principles, Standards, and Procedures. Their efforts first resulted in the 1973 Principles and Standards for Planning Water and Related Land Resources. They then published a 1980 version of the Principles and Standards specifically for Level C planning (Implementation Studies). Ultimately, in

1982 the Principles and Standards were repealed by the Water Resources Council and replaced with the 1983 Principles and Guidelines (P&Gs) which are in place today.

The P&Gs are intended to "ensure proper and consistent planning by Federal agencies in the formulation and evaluation of water and related land resources implementation studies." They cover the implementation studies for water resource project plans of the Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority, and Soil Conservation Service (now the National Resource Conservation Service).

The stated federal objective of project planning is "to contribute to national economic development consistent with protecting the Nation's environment, pursuant to national environmental statutes . . ." The P&Gs require the formulation of various alternative plans "in a systematic manner to ensure that all reasonable alternatives are evaluated." They require the formulation of "a plan that reasonably maximizes net national economic development benefits, consistent with the Federal objective." Other plans which reduce those national economic development benefits "in order to further address other Federal, State, local, and international concerns not fully addressed . . . should also be formulated."

Each alternative plan is to be formulated in consideration of its completeness, effectiveness, efficiency, and acceptability. In evaluating and displaying the alternative plans four accounts are established. They are 1) the national economic development (NED) account, the environmental quality (EQ) account, the regional economic development (RED) account, and the other social effects (OSE) account. The P&Gs state that "a plan recommending Federal action is to be the alternative plan with the greatest net economic benefit, consistent with protecting the Nation's environment (the NED plan) unless the Secretary . . . grants an exception to this rule." Detailed guidance on just how to apply these processes are included in the near 150 page document.

It is interesting to note that in 2007 a process was initiated by the Corps of Engineers to review the 1983 P&Gs and provide revisions within two years. That process now appears to have been taken over by the President's Council on Environmental Quality which has produced a first draft for internal agency review. That process is likely to result in a new version in the years to come.

POLITICS AND POWER

Congress and the Administration

Given the above established processes for federal water resources decision making it is interesting to look at the practical reality of how projects have moved forward in the recent past. Given the complexity of these studies, the cost of these detailed evaluations, the length of time required to complete them, and the ultimate potential for no support from the Executive Branch of government when authorizing legislation is proposed it is not surprising that many project sponsors seek more straight forward solutions.

The Congress of the United States ultimately must pass a law that authorizes and funds a project. In most cases, OMB becomes the decision maker for the administration when it comes to providing the position of the Executive Branch relative to proposed legislation pending in Congress. Typically OMB views the cost of developing a water resource project as excessive and it is virtually a given that the administration's testimony will not support an authorization for construction. Given this reality, many see the obstacles of following the administration's processes only to find authorization for the project not supported by that same administration as a major disconnect. Many sponsors seek other solutions.

Sponsors typically turn to their Congressional delegation to achieve the authorization and funding for their projects. This process is particularly effective in states where a strong and unified delegation exists in support of the benefits of water resource development. It is also a major advantage if the state has Representatives or Senators who are well placed on the right Congressional committees and particularly if supportive Committee or Sub-committee Chairmen are in the mix. Once Congress has decided to support the authorization and funding, in many cases over the objection of the Administration, then the authorization and funding bills get passed and, unless the Administrations issues are significant enough to trigger a Presidential veto, the bills are signed into law. At this point the Executive Branch basically becomes the conduit through which the funding passes in order to implement the project. While this subsequently may require an annual Congressional write-in for continued funding many sponsors see it as the best way to achieve project implementation.

While the current dialog regarding "Earmarks" seems to hint that a continuation of this detailed direction from Congress related to agency spending may be in question, the reality seems to suggest that the process will continue in some fashion. Even the harshest critics of the earmark process seem to have significantly different thoughts when the subject is a needed development in their state or district. One person's "Pork" is another person's much needed project that somehow was overlooked by the Administration!

It all comes down to who makes the decision and how that decision gets made. It becomes a classic tug of war between the Federal budget and what it should be used for and the needs of the Congress to take care of the districts and states which elect its members. It is a great process to watch and study and interestingly it doesn't seem to be much about whether the players are Republican or Democrat but rather about whose project is at stake and what current power and politics exist.

WHAT FACTORS SHOULD BE CONSIDERED?

<u>Benefits</u>

One would hope that no matter which path is pursued toward the authorization and funding of water resource projects that the driving force would be that there are significant benefits to be achieved with the development of the project. The real issue becomes what kinds of things count as benefits and how large are those benefits. Our water resource history would show that early projects were based upon the benefits of agriculture. Crops produced and wages paid were the foundation. Later flood control damages avoided, municipal water delivered, and electrical energy produced were added.

Ultimately recreation and fish and wildlife benefits became part of that mix. The existence of the Environmental Quality account in the P&Gs attests to the continuing importance of those environmental issues.

It is likely that early projects were seen as the only way to stabilize an emerging economy that could support settlement in some parts of the West. Continued growth in many of those areas likely brought the need for additional supplies in the form of expanded capacity or additional projects. It now seems that some of that continued growth is being viewed as a negative by some and many new or expanded projects are facing the issue that constituent groups oppose additional water resource development because they do not want the additional growth. We seem to be moving from the “Build it and they will come” approach to the hope that if we do not build it they will not come. There are seriously differing views about this approach which suggests that by not providing additional water supply then growth can be limited. This author doubts the validity of that approach except when the limited supply or the high cost of that supply becomes such a disincentive that even the existing population no longer desires to stay in residence. In my opinion, long before that time the local population changes its political leadership and begins to support the development of additional supplies. In general, it seems that as long a population continues to increase the need will exist, on the part of public utilities and project sponsors, to continue to find additional supplies to meet the legitimate needs of the people.

Costs

The era of billion dollar water projects is assuredly upon us. It is very common to see projects with total construction costs in the $500 million range. A few being discussed are several billion and on the upper end are some that begin to approach $100 billion.

One of the most common responses from OMB relative to proposed projects is that the cost is too high. When attempts are made to balance the federal budget or reduce the national debt these costs are easy to target as potential cuts. The reality is that once a water resources project is started it is very difficult to discontinue that investment, abandon the potential benefits, and deal with the stranded or sunk cost. It has happened but not often. The more common approach is to reduce funding, stretch the construction period, save the money now, and ultimately drive the total costs higher. It is easy to see why OMB fights so hard to avoid the authorizations in the first place.

One other area of cost that has become increasingly important is that of costs avoided. In the water resources world this has most commonly been applied to flood damages and Indian water rights settlements. The responsibility of the United States and the States to meet the treaty obligations of the native peoples is huge. Many of the contemporary water resources projects are being supported based upon the need to meet those obligations. Real water resources benefits exist for these projects and in addition by resolving these native claims significant litigation costs are avoided. It has become a strong argument for the development of new projects.

It can make a great deal of sense to use a tool like the benefit to cost ratio to help the decision maker. From the above, however, it seems rather easy to see that the decision makers have very different perspectives. OMB seeks to limit federal spending, balance the budget and reduce the deficit. Congress seeks to meet the needs of its electorate. The electorate likely supports the reduction of the federal budget and the deficit but sees significant spending going elsewhere to programs they may not support. When projects to build bridges to nowhere get funded no one is very happy. In the face of that choice they prefer to get their share. They vote and Congress does what Congress does. It is a problem that the federal budget is so large; but it is a disaster if I don't get mine!

Priorities

Even with a clear and commonly held view of the benefits and the costs of proposed water resource development projects there comes the issue of priorities. As among any number of well justified projects which one should be developed first? Should projects supported by the Administrative processes involving P&Gs have priority over those authorized over the objection of the Administration? Should Congress give priority to its authorizations over the projects supported by the Administration? On a broader scale should the development of new authorized projects have a budget priority over future planning? Should new projects have a priority over operation and maintenance of existing projects? Should new projects have priority over the Administrative costs of running the agency?

It is an interesting budget exercise. It works like this. Each year OMB provides a target budget for the Administrative agency, the agency formulates its total budget to that target level, the agency's budget is reviewed and modified by OMB on its way to the President, the President submits the government's budget to the Congress, Congress holds hearings, debates the issues, and ultimately passes an appropriations bill, and the bill is sent to the President to be signed into law. OMB gets several bites of the apple!

It is not uncommon for OMB to reduce the agency budget and for Congress to increase the agency budget while adding its own preferences for spending as write-ins or earmarks. It is through this complex process that spending decisions are made. It's a bit like watching the making of sausage!

A LOOK TO THE FUTURE

Less Federal

Given the current state of the US economy it seems only logical that securing significant funding for water resource development projects in the near future will be very difficult. The current and expected federal deficit and debt will surely drive us toward reduced federal spending in general. Fighting wars on two fronts, the looming costs of a resolution to the health care issue, and the yet to be tackled issue of social security challenges seems to suggest that current national priorities will not soon shift to water resources. It is a safe bet that less federal funding will be available in the next decade.

Less State

Those very same economic conditions are driving state governments to significant cost cutting measures. States like California seem to be is serious trouble. Many states are reducing staff, limiting travel, delaying projects, and in some cases even raiding their future water development funding programs just to balance the state budgets. It also seems logical that some of the cuts occurring at the federal level will shift costs to the state level. It is a safe bet that less state funding will be available in the next decade or so.

More Cost Sharing

Joint efforts for the most critical water resource efforts seem to make the most sense. One potential opportunity is for bonding for development. With interest rates at historic low levels and a shaky stock market investment outlook for many, the potential for public bonding by project sponsors would seem to be an attractive option. If investors could buy state sponsored revenue or general obligation supported bonds for the construction of infrastructure it would seem those bonds would be seen as relatively attractive investment options. The biggest obstacle might be that the bond rating of some of those bonds might not rise to an attractive level in these difficult economic times. In general, however, it seems that to get critical projects developed it well require a cost sharing approach of all the relevant players.

Smaller Development

These realities lead the author to suggest that future projects will need to be smaller. Trying to convince funders to begin projects that cost hundreds of millions or even billions of dollars will be an extremely tough battle. Smaller chunks might have a better chance.

Align the Stars

Getting just the right water resource development package put together has never seemed more important. Critical support by a state's Congressional delegation will be essential. Agency support at the state and federal level will be important. The minimization of negative impacts to the environment and the endangered species will be critical. Paying attention to the energy needs of building and operating the project will be vital. Even with all these bases covered it may take an improved or at least an improving economy to gain the needed support.

Being able to tell the story of why any particular potential project should be moved forward to development will become an absolute. Having the answers regarding what those expected benefits are, what the realistic costs might be, and why the state or federal government should invest in this project will be vital. Investing some time and money into the planning for the project will pay off. We will all need to keep in mind that opposition will be there and that competition for limited funding will be even more intense. Providing water resource benefits is a worthwhile objective but it won't go far if those same benefits could be achieved by the user being able to pay a more equitable share.

Perhaps it has always been that making these water resource development decisions required careful attention to the economic realities of the time. The realities of the current time seem a particularly difficult backdrop for future development. Tough decisions lay ahead and only sound planning and solid decision making will position the water resources world for the future.

GLENN-COLUSA IRRIGATION DISTRICT WATER BALANCE MODEL: A FOUNDATIONAL COMPONENT OF A DISTRICT RESOURCE MANAGEMENT PLAN

Thaddeus Bettner, PE[1]
Grant Davids, PE[2]

ABSTRACT

Glenn-Colusa Irrigation District (GCID) is in the process of developing a Resources Plan (Plan) to establish improved policies and decision making processes to better and more actively manage its available water supplies. The first element of the Plan will address Water Supplies and Transfers; it will be developed through evaluation of the district's recent historical and future water demands relative to available surface water and groundwater supplies. The analyses will reveal the probabilities, magnitudes and durations of possible future water supply shortage and surplus conditions. When combined with supporting legal and institutional review, the analyses will provide a basis for managing available water surface and groundwater supplies, shaping conjunctive water management policy, and evaluating potential surface water transfers.

GCID is developing a water balance model, including related refinements to the District's water measurement, data management and reporting systems, to analyze historical and possible future water supplies and demands. The water balance will be calculated on a monthly time step for up to ten consecutive years, including winter months when rainfall is appreciable and irrigation demands are generally low. Individual water balances will be prepared for each of GCID's ten water operator areas, which can be combined to form the balance for the overall District. This paper provides a background description of GCID and discusses ongoing development of the water balance model and related improvements to GCID's flow measurement and data management procedures.

DESCRIPTION OF GLENN-COLUSA IRRIGATION DISTRICT

Overview

GCID's appropriative water rights on the Sacramento River began with an 1883 filing posted on a tree by Will S. Green, surveyor, newspaperman, public official, and pioneer irrigator. His first claim was for 500,000 miner's inches under 4 inches of pressure and led to the establishment of one of the earliest and largest water rights on the Sacramento River.

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

[1] General Manager, Glenn-Colusa Irrigation District, P.O. Box 150, Willows, CA 95988; tbettner@gcid.net
[2] President, Davids Engineering, 1772 Picasso, Suite A, Davis, CA 95618; grant@de-water.com

necessary for the district to refinance in the 1930s. Additionally, the United States purchased lands within GCID during this period that would later become three federal refuges totaling approximately 20,000 acres.

Today, after surviving many challenges, GCID is the largest irrigation district in the Sacramento Valley. Located approximately eighty miles north of Sacramento, California, on the west side of the Sacramento River **(Figure 1)**, the district encompasses approximately 175,000 acres, including 141,000 planted to agricultural crops, with rice being the dominant crop owing to the heavy clay soils and adequate water supply. Additionally, there are more than 20,000 acres within the three federal wildlife refuges and 5,000 acres of private lands managed to provide wildlife habitat. Winter surface water supplied by GCID to thousands of acres of rice land provides additional valuable habitat for migrating waterfowl during the winter months.

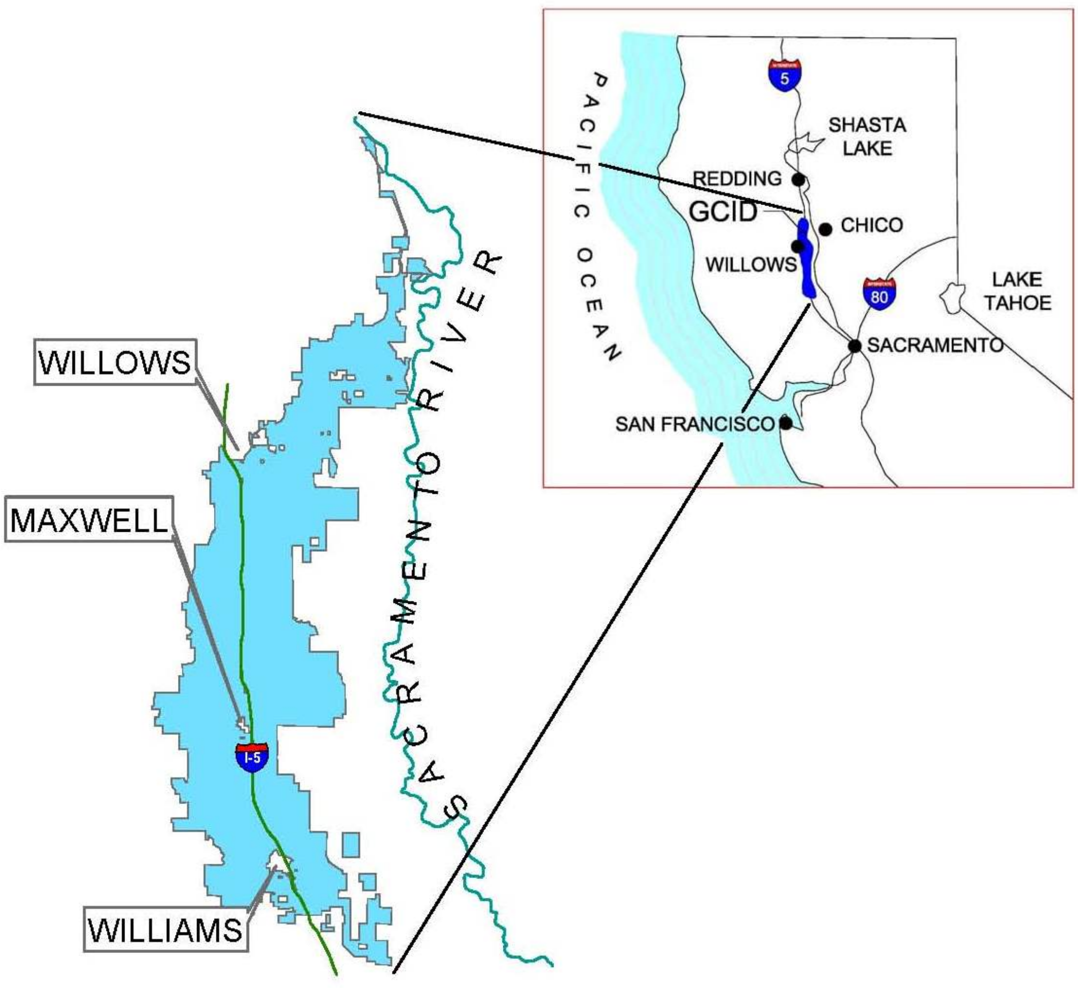


Figure 1. Map of GCID

GCID's main pump station and fish screen structure located near Hamilton City, with a maximum capacity of 3,000 cubic feet per second (cfs), is the largest diversion from the Sacramento River. The District's 65-mile long Main Canal conveys water into a complex system of nearly 1,000 miles of canals, laterals and drains constructed mostly in the early 1900s.

In 1990, the GCID's Sacramento River diversion was identified as a significant impediment to the downstream migration of juvenile salmon. Following the state and federal listing of the winter-run Chinook salmon as endangered under the Endangered Species Act, pumping restrictions were imposed on GCID by a court-ordered injunction, preventing GCID from diverting its full water entitlement. A long-term solution was developed to provide both safe fish passage past GCID's pump diversion and a reliable water supply to GCID by allowing them to divert their maximum capacity of 3,000 cfs. Key components of the solution included enlargement and improvement of the fish screen structure and the construction of a gradient control facility in the main stem of the Sacramento River to stabilize the river channel and ensure flow to the pump intake. These facilities were complete in 2002.

Surface Water Supplies

GCID holds both pre- and post-1914 appropriative water rights to divert water from the natural flow of the Sacramento River. GCID also has adjudicated pre-1914 water rights under the Angle Decree, issued in 1930 by the Federal District Court, Northern District of California, to divert water from the natural flow of Stony Creek, a Sacramento River tributary. In addition, as the successor in interest to Central Canal and Irrigation Company, GCID has, under a May 9, 1906 Act of Congress, the right to divert up to 900 cfs from the Sacramento River (Pub. L. No. 151, Ch. 2439).

From its first diversions until 1964, GCID relied upon its historic water rights and adequate water supply from the Sacramento River. The Sacramento River watershed encompasses 27,246 square miles and has an average runoff of about 22.4 million acre-feet. This is nearly one-third of the state's total natural runoff. In 1964, after nearly two decades of negotiations with the United States, GCID along with other Sacramento River water rights diverters entered into "Settlement Water Contracts" with the Bureau of Reclamation (Bureau). These Settlement Contracts were necessary at that time to allow the Bureau to construct, operate, and divert water for the newly constructed Central Valley Project (CVP). The contract provided GCID with 720,000 acre-feet of base supply during the months of April through October and 105,000 acre-feet of purchased CVP water during the months of July and August. The 825,000 acre-feet annual entitlement recognized under the settlement contract is inclusive of GCID's entitlement recognized under the Angle Decree, which, on average, yields about 15,000 to 18,000 ac-ft/yr. During a designated critical year when natural inflow to Shasta Reservoir is less than 3.2 million acre-feet, GCID's total supply is reduced by 25%, to a total of about 619,000 acre-feet.

Additionally, the District holds a water right under a State Water Resources Control Board (SWRCB) permit to divert “winter water” from the Sacramento River between November 1 and March 31 at a rate of up to 1,200 cubic feet per second (cfs). This water supply is used for rice straw decomposition, maintenance of waterfowl habitat, and minor fall, winter, and early spring irrigation. The permit provides 150,000 acre-feet for rice straw decomposition and 32,900 acre-feet for crop consumption.

Groundwater Supplies

Approximately 200 privately owned groundwater wells are located within GCID’s boundaries. Most of these wells draw from the Tehama Formation at depths ranging between 200 and 500 below ground surface. Additionally, as part of program to explore deeper aquifer systems, GCID has completed construction of three deep wells and plans for a fourth. These wells were designed and constructed to draw from formations generally below depths of 700 feet to minimize the likelihood of interference with shallower, private wells.

In recent years, GCID has supplemented its available surface water supplies with groundwater from local privately owned wells. It has accomplished this with a voluntary conjunctive water management program. This program involves more than 100 private landowners who are reimbursed by GCID for each acre-foot contributed to GCID’s supply. This program has produced up to 67,000 acre-feet of supply in a single year as a means of offsetting critical year surface water curtailments. However, impacts resulting from competing local needs for groundwater as well as air emission regulations have resulted in more restricted use of groundwater.

Water Conservation

In addition to relying more on groundwater to offset surface water shortages, GCID has an aggressive drainwater recapture program involving gravity and pumped diversions from drains into district laterals for supply to farms. It is estimated that GCID currently recycles approximately 155,000 acre-feet annually. Drainwater not recaptured by GCID is available to and is an important supply source for some downstream water suppliers, including Provident, Princeton-Codora-Glenn Irrigation District, Maxwell Irrigation District, and the Colusa Basin Drain Mutual Water Company.

Additional water conservation measures appropriate to the conditions within GCID include conveyance system automation, district-level water measurement, and farmland return flow measurement. Precision farming techniques, laser land leveling, micro-irrigation, and other on-farm irrigation technology improvements have been used effectively within GCID in the last decade to improve water use efficiency and reduce diversions in times of shortage.

Water conservation measures are typically the most expensive options and can be in conflict with the regional water management characteristics of the area. The hydrologic characteristics of the region that GCID lies within can be described as a “flow-through” system, in that the vast majority of the water not consumptively used returns to drains and is rediverted by others, recharges the regional aquifer to the benefit of groundwater pumpers within and outside of GCID, or returns to other waterways and is reused downstream. Therefore, the actions of an upstream district such as GCID can have a considerable effect on downstream areas.

A RESOURCE PLAN AS A FRAMEWORK FOR IMPROVED DISTRICT MANAGEMENT

GCID's core purpose is to provide reliable, affordable water supplies to its landowners. Fulfilling this purpose requires that GCID manage its water, financial, human, and other resources in a strategic, integrated manner. Management processes that were well designed at the time and have served the District reliably for many years are being reviewed and, where necessary, revised in response to new challenges and changing conditions. The district resource plan will document these processes to serve as a basis for policy formulation and management decision making. Some of the more important challenges to district water supplies and the principal elements of the GCID resources plan are described in the following sections.

Challenges to GCID Water Supplies

As previously noted, according to its settlement contract with the federal government, GCID's Sacramento River supplies can be cut by 25% when Shasta Reservoir inflow is less than 3.2 MAF. This represents a supply reduction of more than 200,000 acre-feet in years when shortages occur, or about 1.4 acre-feet per irrigated acre. Historically, these shortages have occurred about 10% of the time; however, the effects of climate change on precipitation and runoff patterns could result in more frequent shortages.

Traditionally, GCID has responded to water supply shortages by increasing production of groundwater and by intensifying drainwater recapture operations, where possible. Increased frequency of shortage means that GCID will reply on these supply augmentation measures more frequently, with unknown effects on groundwater conditions and downstream water suppliers and irrigators.

GCID's Sacramento River "winter" water right has become a critical supply source because it facilitates rice straw decomposition, a relatively new, environmentally friendly farming practice that offers an alternative to rice straw burning, and helps to sustain critical winter waterfowl habitat. However, Sacramento River diversions under GCID's winter water right are subject to Term 91, a provision applicable to all appropriative rights with a priority date after August 16, 1978. Essentially, Term 91 requires that GCID suspend diversions under its winter right whenever the State Water Project and/or federal Central Valley Project are making releases of stored project water to satisfy water quality regulations in the Sacramento-San Joaquin Bay-Delta.

To the extent that Term 91 reduces GCID's ability to divert winter irrigation water, particularly in the months of February and March, landowners have little choice but to rely on groundwater to meet their needs. Winter irrigation demands in GCID, while still small relative to summer demands, are increasing, due to expansion of vegetable and tree crops.

Resource Plan Elements and Objectives

GCID's Resource Plan will address water supplies, water transfers, operations and maintenance, and finances. A summary of the key issues being addressed in each plan area is presented below.

Water Supplies. The Plan will analyze various water supplies available to meet existing and future water demands within GCID. The permits, licenses and contracts under which GCID is allowed to divert surface water will be inventoried. For each water supply source, the following attributes will be evaluated: conditions under which water may be diverted (purpose, period, place of use; diversion limits, etc.); hydrology and water supply availability; and historical diversion and use by GCID. For each supply source, an assessment will be made regarding its vulnerability to possible future legislative or regulatory action, climate change, and other factors that are reasonably foreseeable and definable. Based on the preceding assessment, monthly (or possibly bi-monthly) time series of water supply availability will be developed for each surface water source. Different time series may be developed reflecting different assumptions about future water supply reliability. Groundwater conditions, availability, development, and use within GCID will be characterized. This will involve describing the hydrogeology of the region based on available production and gas well logs, hydrogeologic data, and other information. The locations and capacities of existing production wells will be compiled and mapped (within the limits if available data). The existing Stony Creek Fan Integrated Groundwater and Surface Water Model (SCFIGSM) or a regional model of the Sacramento Valley (presently under development) will be reviewed and updated, if necessary, based on the preceding task. The model(s) will be used to evaluate alternative groundwater development and use scenarios as a means of establishing practical, sustainable operational limits.

Water Transfers. The Plan will characterize historical and future water transfers for purposes of quantitative analysis. GCID has historically engaged in water transfers, including annual transfers within the basin and occasional transfers out of the basin. These historical transfers will be documented in terms of monthly transferred water volumes for purposes of analysis. In addition to maintaining historical in-basin transfers, GCID intends to meet its obligations to the Sacramento Valley Water Management Agreement (Phase 8) and to develop a decision framework for evaluating potential future in basin and out of basin transfers beyond Phase 8. Under this task, hypothetical future water transfers will be characterized for purposes of analysis. This will take the form of rules defining the frequency of potential transfers, and related schedules of monthly transferred water volumes.

Operations and Maintenance. The Plan will focus on continued reliability by GCID to meet customer water needs at an affordable cost. The Plan will include a complete evaluation of all District facilities and privately owned facilities used by the District to provide a basis and priorities for annual maintenance activities and capital improvement plans. Annual maintenance activities and system improvements will be prioritized by evaluating cost-benefit ratios. The plan will also evaluate the need for increased staffing necessary for efficient year-round operations and requirements for completing system maintenance during narrow system shut periods.

Finances. The Plan will include a master program to provide a basis for long-term financial planning, including reserve funds and carryover, risk analysis of uncertain budget items (e.g., water transfer revenues and power costs) to facilitate scenario analysis for long-term planning, analyze potential impacts of major uncertain budget elements over 5-year period by evaluating best-case, worst-case, and most-probable scenarios, and examine existing rate structures, and analyze a basis for land-based and water charges.

WATER BALANCE MODEL

Objectives

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

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

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

Phased Model Development

The water balance model is being developed in phases in consideration of GCID's needs and resources, and the adequacy historical operations data. The historical data currently available will allow initial model development and approximate calibration. As historical data is improved, the model will be refined, leading to increased confidence in model results and interpretation. Eventually, once system characteristics are sufficiently defined, it is envisioned that the model will be modified to function in a planning mode. In that mode, hypothetical cropping and water demand scenarios will be user definable and the model will calculate associated water demands. Water demands will then be compared to available water supplies under different user definable hydrologic scenarios.

The model will be a "data driven", meaning that various water supply and demand scenarios will be specified through user selection of the data inputs. Water demand patterns for various crop-soil-system-management-weather combinations will be developed, and the user will be able to define model runs by specifying the combinations he wants to evaluate. Initially, the combinations will be developed to represent past, historical operations. Later, different combinations will be developed to represent future, hypothetical scenarios. The demand patterns will be generated by a Water Demand Generator and stored in a Water Information System. Similarly, various water supply patterns will be developed and will be selectable by the user, for example, to represent wet, normal, or dry conditions, or different mixes of surface water and groundwater use. The model will then track flows through the system according to the specified water supplies and demands and designated system characteristics selected in the model. A depiction of the relationship between data sources, the Demand Generator, and the water balance model are illustrated in Figure 2.

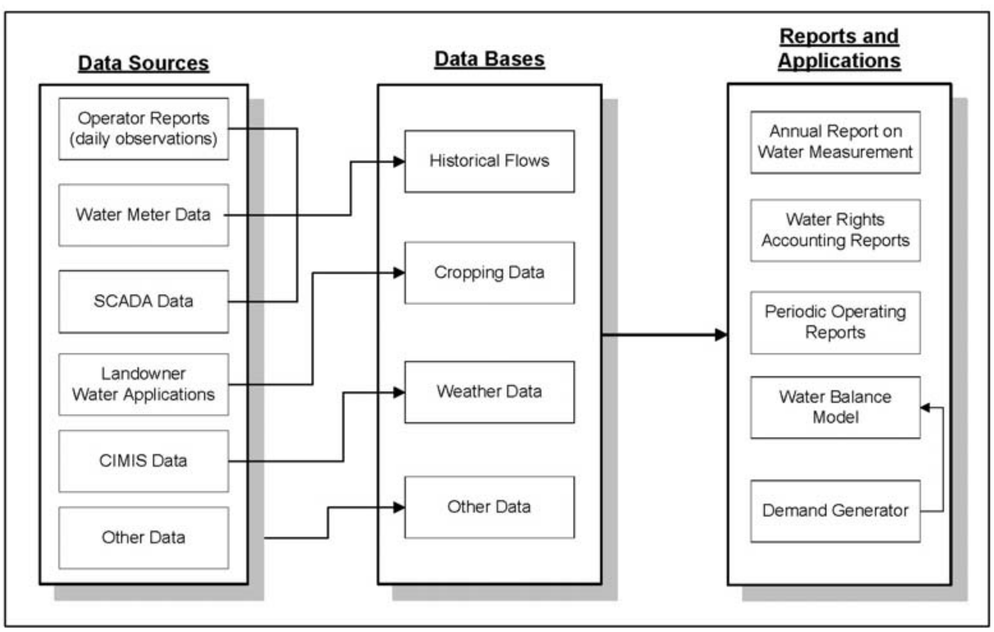


Figure 2. Plan Data Sources, Data Bases, and Reports and Applications

Water Balance Structure

The structure of the water balance (Figure 3) was developed based on consideration of the layout of the GCID irrigation and drainage systems, the structure of GCID's water operation organization, and the availability of historical water operations data. The model domain was defined to include the entire area within GCID, including the three federal wild refuges. The cities of Willows and Williams and several other towns are contained completely within GCID but are not represented in the initial model. Municipal water use within cities and towns, and rural residential water use, is derived entirely from groundwater and is small relative to agricultural water use. Representation of municipal water use may be added to future versions of the model.

GCID is represented by five "accounting centers" shown as boxes within the dashed line in Figure 3. These are the Main Canal, Laterals, Farmland, Drains and Refuges accounting centers, which, collectively account for all water flowing into, through and out of GCID. The accounting centers are connected by flow paths. According to conservation of mass, for each of these five accounting centers and time step, the sum of inflows and outflows, plus any changes in water storage, must equal zero. Historical discharge measurements are available for the flow paths marked with the circular cross symbol. All other flow paths must be independently estimated or determined by water balance closure.

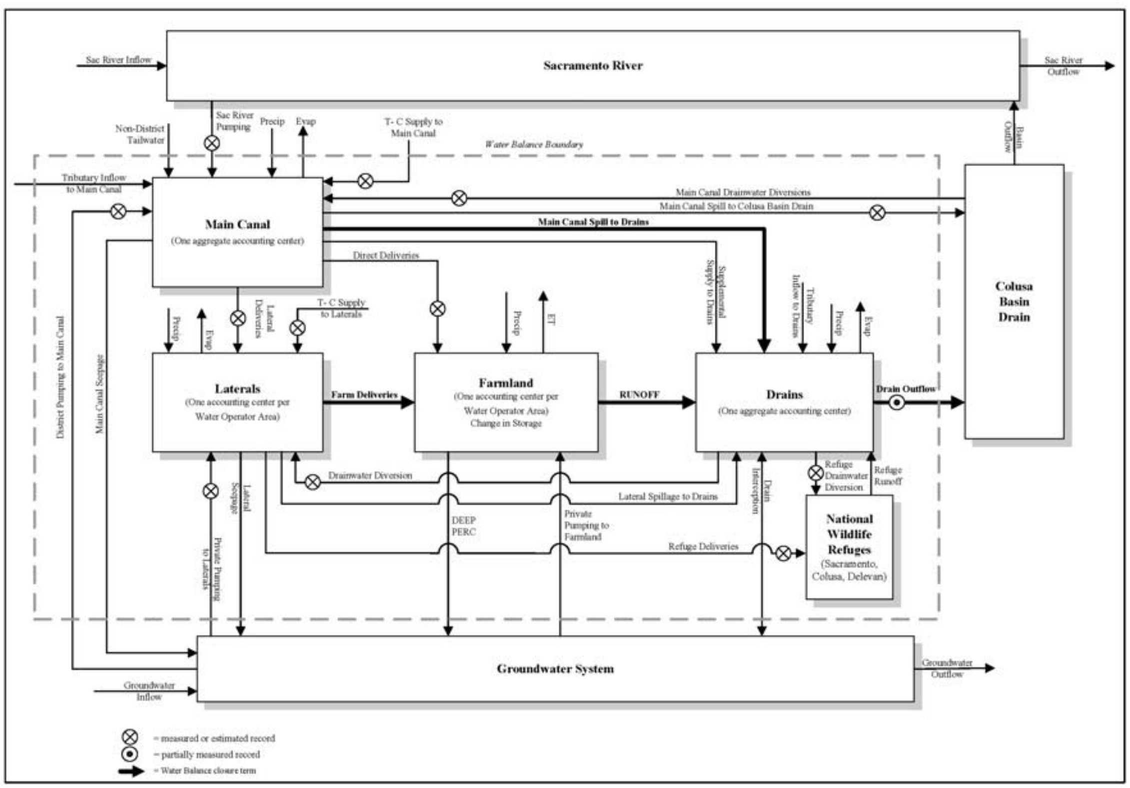


Figure 3. Water Balance

The boxes outside the dashed line in Figure 3 represent GCID's water sources and drainage destinations. The flow paths that cross the dashed line represent the various inflows to and discharges from GCID. As previously discussed, GCID's principal water sources are the Sacramento River and groundwater. Ultimately all water flowing into GCID and not consumed by evapotranspiration (ET) is discharged to either the Sacramento River via the Colusa Basin Drain or to underlying groundwater aquifers.

Main Canal Accounting Center. Reliable records of Main Canal discharge are limited to historical Sacramento River pumped diversions measured near the head of the main canal; no records are available for intermediate locations along the canal. Therefore, the Main Canal will be represented as a single accounting center in the initial model. GCID is in the process of rating several of its Main Canal checks as part of its SCADA expansion program. When sufficient historical records are available at intermediate locations, consideration will be given to segmenting the Main Canal into multiple accounting centers. Among other things, this may allow more spatially discrete estimates of main canal seepage. Dominant Main Canal inflows are pumped diversions from the Sacramento River and deliveries from the Tehama-Colusa Canal (which also are diverted from the Sacramento River at Red Bluff Diversion Dam). Principal Main Canal outflows are deliveries to laterals and direct deliveries to farms adjoining the canal.

Laterals and Farmland Accounting Centers**.** GCID laterals and associated farmland are grouped into ten Water Operator Areas (WOA's), with each lateral belonging entirely to one WOA. Thus, although illustrated as a single accounting center in Figure 3, the water balance will have ten paired Lateral and Farmland accounting centers, each pair representing a WOA. Primary inflows to laterals are measured deliveries from the Main Canal and, for certain laterals, measured deliveries from the Tehama-Colusa Canal. The primary outflow is deliveries to farms. For the Farmland accounting centers, the principal inflows are farm deliveries from laterals and precipitation; major outflows include crop ET, runoff (tailwater) and deep percolation.

Drains Accounting Center. There are several ephemeral creeks that originate in the Coast Range foot hills west of GCID and generally course southwestward through GCID toward the Colusa Basin Drain and eventually to the Sacramento River. During winter and early spring these creeks carry rainfall runoff, with highly variable flows depending on rainfall duration and intensity and storm patterns. Flows typically decrease to insignificant levels by early spring. During the irrigation season, typically beginning in early April, the creeks serve primarily as drains for the collection and conveyance of irrigation return flows, including operational spills from the Main Canal and laterals and tailwater from irrigated farmland. Individual drains (creeks) typically collect return flow from multiple WOA's and a single WOA may discharge tailwater to multiple drains. Also, drains serve as a water source, and in some cases, the sole water source, for certain laterals. Due to this complex arrangement, drains are represented in the initial model as a single water accounting center. Roughly 80% of the drain flow leaving GCID during the irrigation season is measured. Records are maintained of winter creek/drain flow to the extent possible given the need to safely pass storm flows.

Model Flow Path Calculation Procedures and Initial Calibration

Water balance calculations will be performed on a monthly time step with results rolled up to monthly or longer periods for calibration, interpretation, and analysis. Calculation of the historical water balance begins with the Main Canal accounting center, followed by the ten Lateral accounting centers, the ten Farmland accounting centers, and the Drains accounting center in sequence. For each accounting, the associated flow paths are determined from historical measurements or independent estimates or by water balance closure. The flow path selected for closure is typically the one for which there is no historical record and independent estimates are least reliable.

Initial model calibration will focus on matching modeled aggregate to historical Drain Outflow volumes and timing during the irrigation season. This is being approached in the following manner. First, historical records of inflows to GCID have been checked and quality controlled to create the most accurate possible record of total district inflow. Then, independent estimates of crop ET have been calculated using crop coefficients developed specifically for GCID based on 2002 actual ET maps produced using the SEBAL energy balance algorithm. The difference between precipitation, GCID inflow and crop ET (plus any change in storage) represents the total GCID outflow, which is discharged either to drains or to underlying groundwater. Modeled drain flow volumes will be matched as closely as possible to measured volumes by adjusting flows paths between GCID and the underlying groundwater system; namely, Main Canal and lateral seepage and deep percolation of applied water. This will be performed first for the full irrigation season to minimize the effects of storage changes and then on a monthly basis to match drain flow timing as closely as possible.

Model Platform

The water balance model is being coded in GoldSim risk analysis and simulation software. GoldSim is a flexible, dynamic system simulation platform for analyzing, visualizing and simulating the behavior of complex natural, financial, and engineered systems. System simulation software like GoldSim can provide a viable alternative to spreadsheet programs because model inputs, model logic, and results processing can be handled in a modular fashion, where information is made available plainly within the model components rather than hidden in spreadsheet cells. GoldSim is user-friendly and allows the modeler to quickly build model logic and build simple user interfaces for the end-user. It was chosen for this application mainly because of its visual orientation and to allow model operation by users with a wide range in computer expertise.

SUPPORTING IMPROVEMENTS TO FLOW MEASUREMENT AND DATA MANAGEMENT PROCESSES

Like many irrigation districts in the western United States, GCID is in the process of improving its flow measurement and related data management processes. Existing processes have evolved in a manner that adequately supported water operation and administration, but do not necessarily support more recent efforts to refine water management policy and practice in response to existing and anticipated challenges to water supply reliability.

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

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

One major objective of the conversion to a data base environment was to accommodate the growing volume of operational data from SCADA sites. Over time, it is expected GCID's reliance on SCADA will increase and on operator reports will decrease. This trend is typical of many irrigation districts that are implementing SCADA systems for remote monitoring and control of water distribution systems. It is anticipated that the capacity limits of Access will be exceeded and the data base system will have to be migrated to a higher capacity platform, such as SQL server or Oracle. This migration will be relatively straightforward now that data is stored in data base tables. Eventually, GCID intends to house or access all of the data needed for water balance analysis in an integrated Water Information System (WIS). A major consideration in the design of the WIS is to enable routine updates of the water balance model by district staff, without assistance from outside consultants.

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

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

SUMMARY

The development of a Resources Plan is a necessary step in improving policies and decision making processes to better and more actively manage water supplies. When combined with supporting legal and institutional review, the Plan will provide a basis for managing available water surface and groundwater supplies, shaping conjunctive water management policy, and evaluating potential surface water transfers.

At the core of the plan, a water balance model will serve as the best tool to improve the District's water measurement, data management and reporting systems, and to analyze historical and possible future water supplies and demands.

APPLICATION OF CANAL AUTOMATION AT THE CENTRAL ARIZONA IRRIGATION AND DRAINAGE DISTRICT

Robert J. Strand[1]
Albert J. Clemmens, P.E. PhD[2]

ABSTRACT

The Central Arizona Irrigation and Drainage District (CAIDD) began delivering water to users in 1989. Although designed for automatic control, the system was run manually until a homemade SCADA (Supervisory Control and Data Acquisition) system was developed by district employees. In 2002, problems with radio communication and limitations of the homemade SCADA system prompted CAIDD to begin the process of modernization. New spread-spectrum radios and RTUs (Remote Terminal Units) were purchased along with a commercial SCADA package (iFix by GE-IP). In 2005, CAIDD decided to pursue implementation of full automated control of a majority of district check gates. Currently, 125 gates are under remote manual supervisory control and 129 water levels are remotely monitored. CAIDD chose to implement SacMan (Software for Automated Canal Management) under development by the U.S. Arid Land Agricultural Research Center, Maricopa, AZ. The decision was made to only apply full automation at gates that had gate position sensors. Thus purchase and installation of gate position sensors have slowed implementation. To date, five lateral canals have been set up for full automatic control, where SacMan routes flow changes through the canal and uses downstream water level feedback control to correct for any errors that occur. The ditchrider only makes changes at the farm turnouts and district-operated wells. Automation of the Central Main canal has been tested in simulation. Control of this canal requires special treatment, as described in a companion paper. The district is waiting until enough of the canal is ready for automation before it turns automatic controls on 24/7, since this will require some operator training and remote oversight when problems occur. We hope this occurs in the summer of 2010.

INTRODUCTION AND BACKGROUND

CAIDD is headquartered in Eloy, Arizona and services approximately 87,000 acres of agricultural land in south-central Arizona. The district was originally formed in 1964 as part of the Central Arizona Project Association's (CAPA) efforts to bring water from the Colorado River to the Phoenix and Tucson areas. CAPA had been raising money and lobbying since 1946. While the urban populations in the Phoenix and Tucson areas were growing steadily, CAPA needed to show demand for additional water supplies. Dropping ground water levels and problems with recession cracking made the area around Eloy a worthwhile customer for the proposed project. CAPA's efforts were culminated by the signing of the Colorado River Basin Project Act of 1968 by President Lyndon B.

---

[1] Electrical Engineer, U.S. Arid Land Agricultural Research Center, USDA/ARS, 21881 N. Cardon Lane, Maricopa, AZ 85238 bob.strand@ars.usda.gov
[2] Center Director, U.S. Arid Land Agricultural Research Center, USDA/ARS, 21881 N. Cardon Lane, Maricopa, AZ 85238 bert.clemmens@ars.usda.gov

Johnson. This act provided for the construction of the Central Arizona Project (CAP). Construction of CAIDD canals began in the mid 1980's and the initial water deliveries commenced in 1987. By 1990, CAP water was available throughout the district. At that time, all groundwater wells within the district boundaries were leased to CAIDD for a period of 40 years.

CAIDD consists of three major regions, each supplied by a main canal off of the CAP (Figure 1).

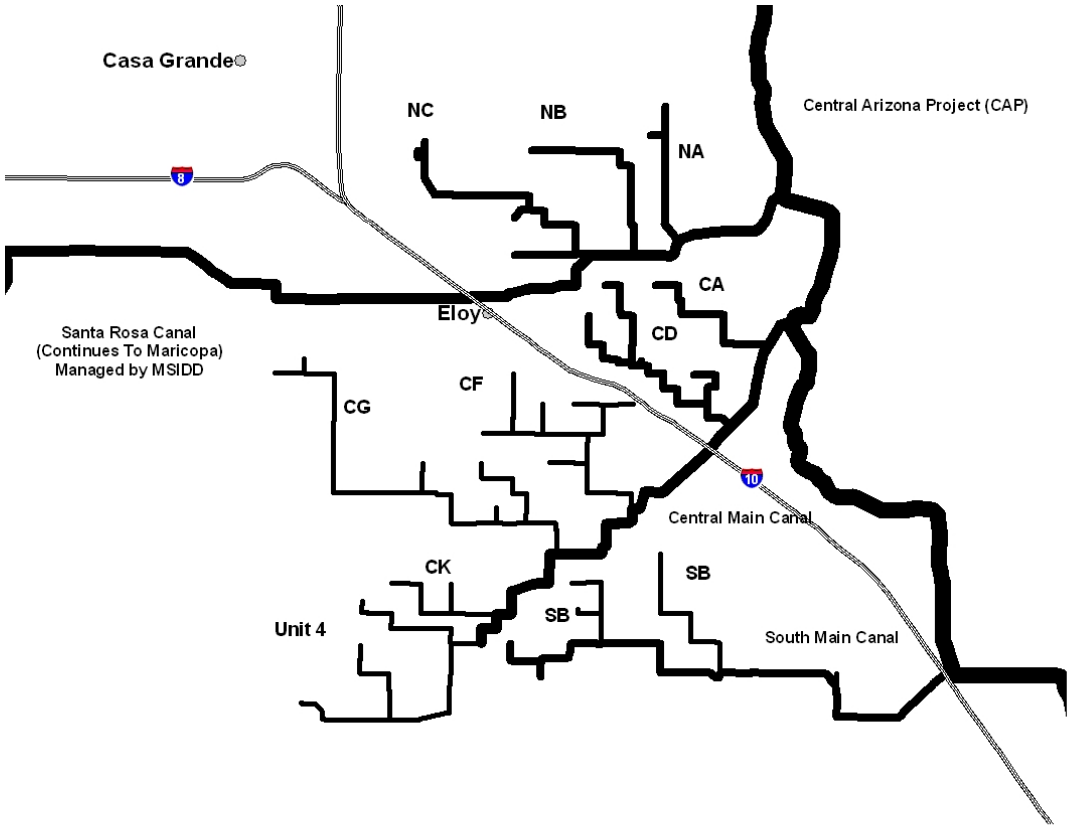


Figure 1. CAIDD Topology

The north region of the system is supplied by the Santa Rosa Canal. This 1200 cfs canal continues past the CAIDD boundaries and services the Maricopa Stanfield Irrigation and Drainage District (MSIDD) and the Ak-Chin Indian Community. Both are located near Maricopa Arizona. MSIDD manages the entire length of the Santa Rosa Canal while CAIDD manages 4 laterals and 5 direct turnouts from the canal. Additionally, there are 46 groundwater wells which either dump directly into the lateral canals, or combine with delivery flows in the grower's canals.

CAP water is delivered to the central region via the Central Main Canal (CMC). The CMC has a capacity of 900 cfs in its upper reaches and supplies 7 lateral/sub-lateral groups. The district also manages 151 wells that either pump into canals or directly into farm ditches.

The South Main Canal (SMC) serves the south region of the system. It has a capacity of 370 cfs and supplies 3 lateral canals. The south region is also supplied by 42 wells.

The canal system was designed with automatic control in mind. Most check structures were originally equipped with three-phase Limitorque motors, and RTU's & pressure transducers manufactured by Automata Inc., Nevada City, CA. The Limitorque motors included positioning circuitry intended to position the gate based on an analog voltage output from the RTU. Communication was over a licensed narrow-band FM radio system.

There are some regulating structures that were designed to be operated manually. Generally, these sites were either located at the end of lateral canals or in areas where power was not readily available. Others are direct turnouts from the main canals. Some of these sites were outfitted with telemetry equipment to allow water level monitoring. All turnouts were equipped with manual gates and solar-powered single-path ultrasonic flow meters.

In 1989, automatic control tests were conducted on the NB lateral, but were unsuccessful due to hardware incompatibilities and the use of a heuristic control method that did not account for pool dynamics.

CAIDD abandoned the original control software supplied with the construction contract and ran the system manually. Eventually, a district employee developed a home-grown SCADA system that implemented the Automata communications protocol. This DOS-based software could control 45 sites. Additionally, CAIDD abandoned the use of the gate positioning circuitry and developed field hardware utilizing electronic timers. These circuit boards, named "KT Boards" after the developer, used two timers to move the gate for either a "Large Bump" or "Small Bump". The time allocated for each size of movement was adjusted with 2 variable resistors on the board.

A single gate movement was implemented using multiple instructions to the RTU. First, the SCADA system sent a signal to the RTU to set the appropriate analog voltage output to full scale to select the movement direction (up or down). Then a signal was sent to move the gate for one of the two increments. On the main canals, a big bump represented a 5 cfs movement, and a small bump was a 1 cfs movement. In order to get a +7 cfs movement, the SCADA system would send a +5 cfs movement and two +1 cfs movements. While this method required many communication exchanges with the field hardware, it did function well within the existing operations.

Recent Modernization

In 2002, the district lost the license for its narrow-band FM radio frequency due to an administrative error. Faced with varying options, CAIDD chose to use serial frequency-hopping spread spectrum radios; avoiding FCC licensing issues for the foreseeable future. With the radio change, the aging RTUs were also replaced. This new equipment was provided by Automata. Additionally, CAIDD replaced their home-grown SCADA system with a commercial package; iFix by GE-IP.

The new RTU was custom programmed with a time-based gate movement routine. The movement time & direction are transmitted from SCADA software as a signed (twos-complement) 16-bit integer value. The magnitude of the transmitted value represents the movement time in 0.1 second increments and the sign determines the direction of the movement. This allowed for the removal of the KT Boards from the actuator system.

In 2004, CAIDD started installing Automata gate position sensors on gates in the northern segment of the district. These sensors house two output devices. The first is a 10-turn potentiometer which gives an absolute gate position. The second sensor is an incremental encoder, which gives a 0/+5 volt square wave output based on gate travel. Both devices are connected to a gear which is driven by a gear rack attached to the gate. For the gear ratio giving a 4 ft full scale absolute position range, the incremental sensor has a pulse width of 0.95 mm.

In order to accommodate the gate position sensor, the firmware on the RTU was upgraded to allow an incremental gate movement by counting each rising edge of the pulsed output. The transmission from the SCADA system is similar to the time-based movement implemented earlier, except that the magnitude of the value represents the number of gate position sensor pulses.

Some of the manually operated check structures were upgraded with electric motors and telemetry. Finally, 14 turnout meters in the North region were replaced with meters from Mace-USA, Kansas City, MO that report to the SCADA system.

To date, 129 sites are outfitted with Automata RTU's, 125 of which control check gates. Thirty three of these gate structures are equipped with the Automata gate position sensor.

Current District Operations — Manual & Supervisory

Constraints CAIDD is a closed, demand-driven system. There are a number of constraints that come into play in the management of the district. CAP requires that demand changes for the Santa Rosa, Central Main, and South Main canals be reported by 9:00 a.m. the day prior. Additionally, CAP only allows two flow changes per day at each of the canal headings. There are occasional exceptions in case of an emergency.

There is also an electric power threshold for the groundwater wells. Should the cumulative power consumption of the wells exceed this threshold at any time in a billing period, the district-wide billing rate essentially doubles for that billing period. Groundwater is less expensive than CAP water, so the district generally uses as much groundwater as possible while still leaving an error margin to avoid the higher charges. Generally the total district delivery is roughly 50% ground water and 50% CAP water.

Finally, there are manpower constraints. The first shift in the dispatch office arrives at 5:00/6:00 a.m. (peak-flow months/remainder of the year). The office is manned until 4:30 p.m. throughout the year. The SCADA controls are generally unmanned through the night. Dispatch personnel and the senior ditchrider rotate weekly in an emergency on-call capacity and carry a cell phone with a published number.

Ditchriders arrive at 6:00/7:00 a.m. During busy times, there is one ditchrider available to make delivery changes until 9:00 p.m. Otherwise, delivery changes are generally completed by 2:30/3:30 p.m. On weekends, there is one dispatcher, and delivery changes are generally concentrated earlier in the day so that ditchriders can minimize their overtime hours.

Manual Control From the start of water deliveries in 1989, district personnel began to develop a knowledge base for manually operating the system. Vertical staffs were attached to all check gates and operators, equipped with tape measures marked in 0.01 ft increments, began developing gate calibrations for each check structure in the system. Today, the operators still carry notebooks with these calibrations to make manual adjustments. Turnout adjustments are generally based on the reading from the turnout meters.

Supervisory Control Through the SCADA system, dispatchers are able to route flow changes through much of the system. Flow adjustments are input to the SCADA system. Based on the availability of a gate position sensor, the flow changes is either converted to a number of pulses, or seconds of gate movement (both based on field calibrations), and then sent to the RTU. Water levels are automatically polled every 20 minutes. Through the SCADA interface, operators can manually force an RTU to poll the water level.

Demand Management Outside of managing the canals through the SCADA system, one of the major tasks of the dispatchers is to take demand orders from the customers and place supply orders with CAP. This is generally a 6 step process:

1) District customers place their orders over the phone or in person by 9:00 a.m. the day before the changes are needed. Dispatch office personnel write these orders on a large whiteboard in the dispatch office and also enter the information into water accounting software.
2) At 9:00, dispatchers accumulate the orders for the North region of the system and phone the totals to MSIDD staff so that they can include those changes in their order for the Santa Rosa Canal.
3) CAIDD personnel determine any changes to groundwater wells for the following day, write these changes on the whiteboard, and enter them into the computer.
4) They then determine preliminary total inflows required for the CMC and SMC systems at two different times in the following day. The time of day varies based on how the order times for a particular part of the system are grouped, but generally the first time is at the start of the dispatcher's morning shift and the other is sometime in the afternoon. Sometimes, there is some data wrangling as entries wind up missing from either the whiteboard or the computer, or both.

5) Next, they examine the behavior of each system (CMC & SMC) to determine an overall overage/shortage for the prior day. If a system has been slowly dropping over the prior day they will add extra flow to their order for the next day to compensate, or vice versa. Based on the magnitude of the drift in the main canals, the times may be adjusted. These changes and the timing of the orders are based on experience.
6) Finally, they call CAP and place the order for the next day.

The bulk of the dispatcher's day is spent taking orders & payments from the customers, entering meter reads, and managing the canal levels & routing flow changes down canals through the SCADA system. During the spring and summer, the ditchriders are kept busy making delivery changes and reading well, pump, and turnout meters, cleaning trash racks and removing weeds. In the off-peak times of the year, they assist with maintenance on the canals.

AUTOMATIC CONTROL

Overview of the ALARC Approach

Feedforward Control Various methods have been developed to calculate a schedule for routing known flow changes through an open channel system. One of the problems with routing flow changes in an open channel is wave dispersion. A flow change that originates as a square wave at the upstream end of a pool will arrive gradually at the downstream end. Wiley (1969) developed a methodology, called gate stroking, which addressed this problem. However, depending on hydraulic properties of the pool, gate stroking can result in unrealistic changes in inflow.

Bautista and Clemmens (2005) proposed the use of a simple volume compensation method based on the change in pool volume from one steady state to another. As shown in Figure 2, for a given Manning n and downstream water level, the pool volume increases as the steady-state flow rate increases.

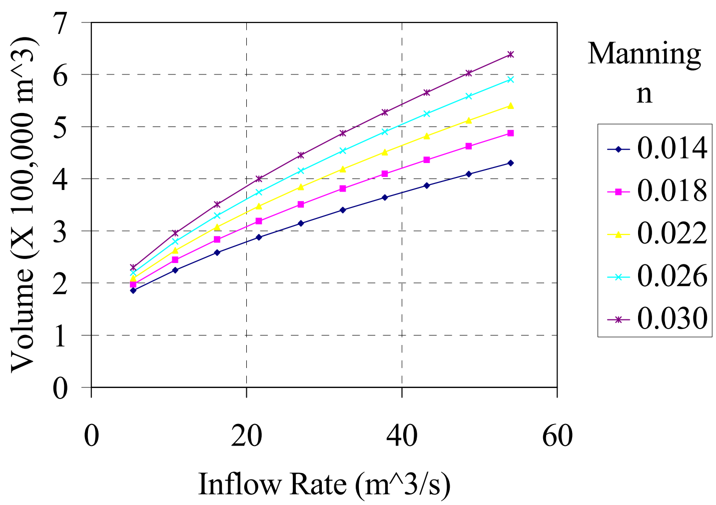


Figure 2. Pool Volume as a function of Inflow & Manning n at a given downstream depth

The delay time, τ, for routing a flow change through the pool is given by

$$\tau = \frac{V_{Q_2} - V_{Q_1}}{Q_2 - Q_1} \tag{1}$$

Figure 3 shows an example of a 25 cfs change being routed through a pool with an initial inflow of 35 cfs and a turnout delivery of 10 cfs. If the volume change required to go from an initial steady-state flow of 35 cfs to a final flow of 60 cfs is 45000 ft^3, then the delay time, τ, is 45000/(60-35)/60 = 30 minutes. If the upstream gate is opened at 3:30, then the required volume will have accumulated in the pool at 4:00 at which time the downstream gate is then opened.

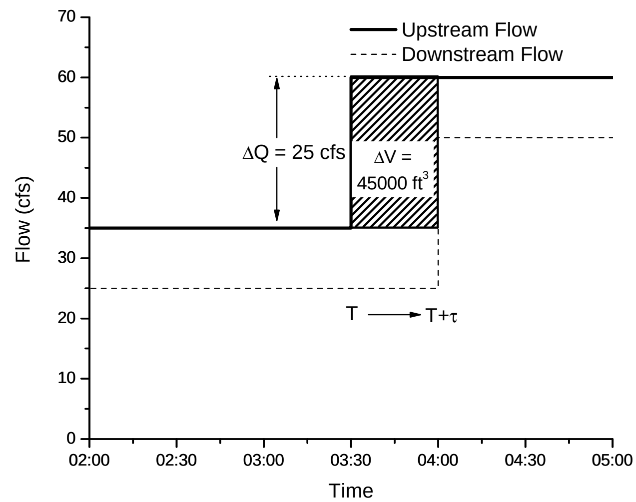


Figure 3. Feedforward Control Example

Local Upstream Level Control Local upstream level control (LULC) is a single-input, single-output (SISO) type of feedback control that adjusts the local gate at regular intervals to bring the upstream water level to the setpoint (Figure 4). This type of level control does not manipulate the inflow at the upstream end of the pool.

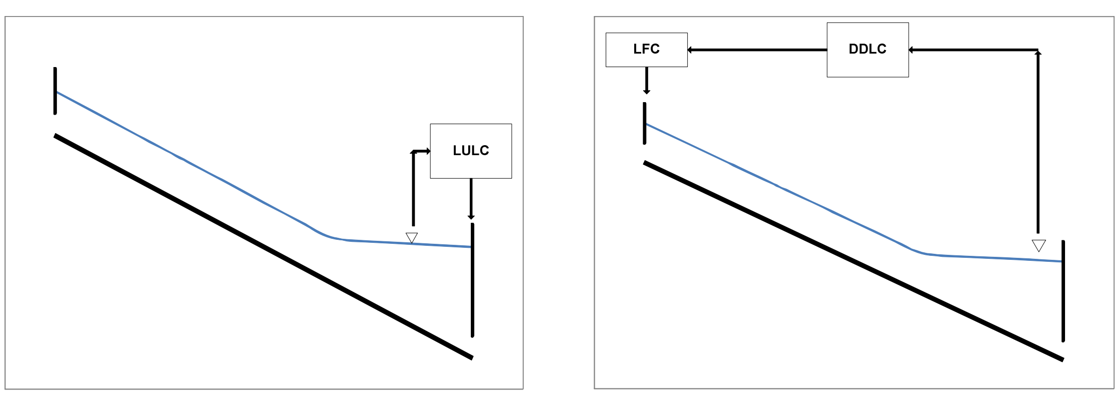


Figure 4. Local Upstream & Distant Downstream Water Level Control

Should the flow coming from immediately upstream drop, the gate will close to maintain the local upstream depth and vice versa. This means that any errors in pool inflow are passed downstream. Since the controller is matching local inflow and outflow, the response of this type of control is generally quite fast. However, in a situation where multiple pools are controlled by individual local upstream level controllers, any error between upstream inflows and the combined outflows in the controlled polls will be concentrated in the last pool. Additionally, flow disturbances caused by controllers at upstream pools can be amplified by the controllers further downstream, possibly causing instabilities.

Distant Downstream Level Control In its elementary form, distant downstream level (DDLC) moves the downstream water level to setpoint by modifying the flow through the upstream gate at regular intervals (Figure 4).

The ALARC formulation of DDLC adjusts the flow setpoint for a local flow controller (LFC) at the next upstream gate. By separating the feedback control from the local flow control, the hydraulic properties of the regulating structure are removed from feedback formulation. This makes the determination of the feedback parameters much less arduous as the parameters are determined from a linearized hydraulic response of the pool.

In DDLC, flow errors are moved upstream, eventually matching the upstream inflows with total pool outflow. One downside is that this type of control can be quite slow. This is due to the long delay time between a change at the upstream end and the response at the downstream end.

The basic form of distant downstream control is SISO. When DDLC is applied to consecutive pools with robust flow control at each site, this formulation can reduce the propagation of errors in the downstream direction. However, like upstream level control, instabilities can occur due to pool interactions and resonance. To address these issues, the ALARC control formulation utilizes a state-space approach to develop multiple-input multiple-output (MIMO) controllers for both LULC and DDLC. Refer to Clemmens and Strand (2010b) for details on the development of controllers based on the state-space approach.

The LFC maintains the flow through the local regulating structure at a specified flow setpoint. This setpoint can be modified by flow changes prescribed by the feedforward control as well as those generated by the DDLC.

The ALARC approach allows the flexibility of combining both types of level control. Consider the profile view of the NB lateral at CAIDD (Figure 5). The pool upstream of NB-13 has little storage and the turnout at that site is very sensitive to changes to the water level in that pool. Additionally, the pool between NB-14 and NB-16 has two inverted siphons that greatly increase the time for a flow change to reach NB-16. Finally, the gates at both NB-16 and NB-17 are manually operated.

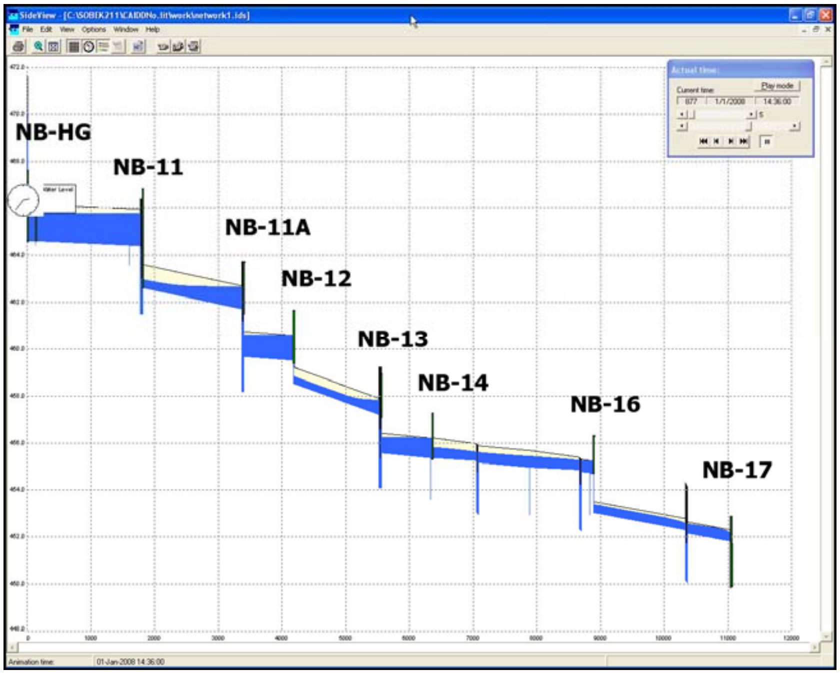


Figure 5. Side View of NB Lateral

As shown in Figure 6, utilizing the fast response of LULC at NB-13 avoids large fluctuations caused by the lack of storage at the site and maintains the turnout flow. The state-space feedback essentially skips that pool. During daytime operation, it is best to avoid controlling water levels at sites with manually operated gates. With no flow control at such a site, improper or poorly timed gate adjustments can have a large impact on the controller response for the whole lateral. Nonetheless, it is advantageous to enable control at such a site during long periods with no delivery changes in order to drive the level to setpoint. Given the long delays in the NB-16 pool, creating a separate, highly damped state-space feedback loop allows the level to be controlled without the large fluctuations in the pool directly impacting the loop that controls the upstream portion of the lateral.

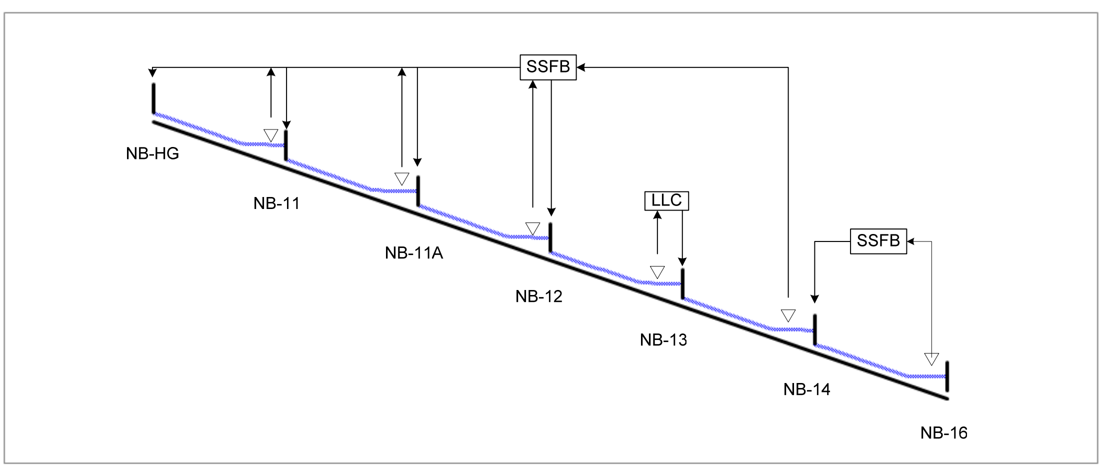


Figure 6. Combining LULC and SSFB

Control Software

SacMan (Software for Automated Canal Management) is a research tool developed by the ALARC to test control methodologies (Clemmens and Strand 2010a). SacMan consists of two programs. SacMan Order (Figure 7) provides an interface for entering orders and calculating a feedworward schedule.

There are currently three types of orders available. The first is "Start of Day". This order type is used to specify orders already starting. It is used to establish the initial conditions if the software has not been used for some time. The second is a typical future order specifying the time that a change is to arrive at its destination. Using Eq. (1), the feedforward calculation for this type of order starts at the destination point and delay times are then computed working in the upstream direction. The third type is an "ASAP" order to handle the routine question of "How soon can you get water to me?" This order type calculates the feedforward schedule starting at the top of the system, summing the delays computed from Eq. (1) in the downstream direction, and computes the arrival time if the schedule were initiated five minutes from the time of the date entry.

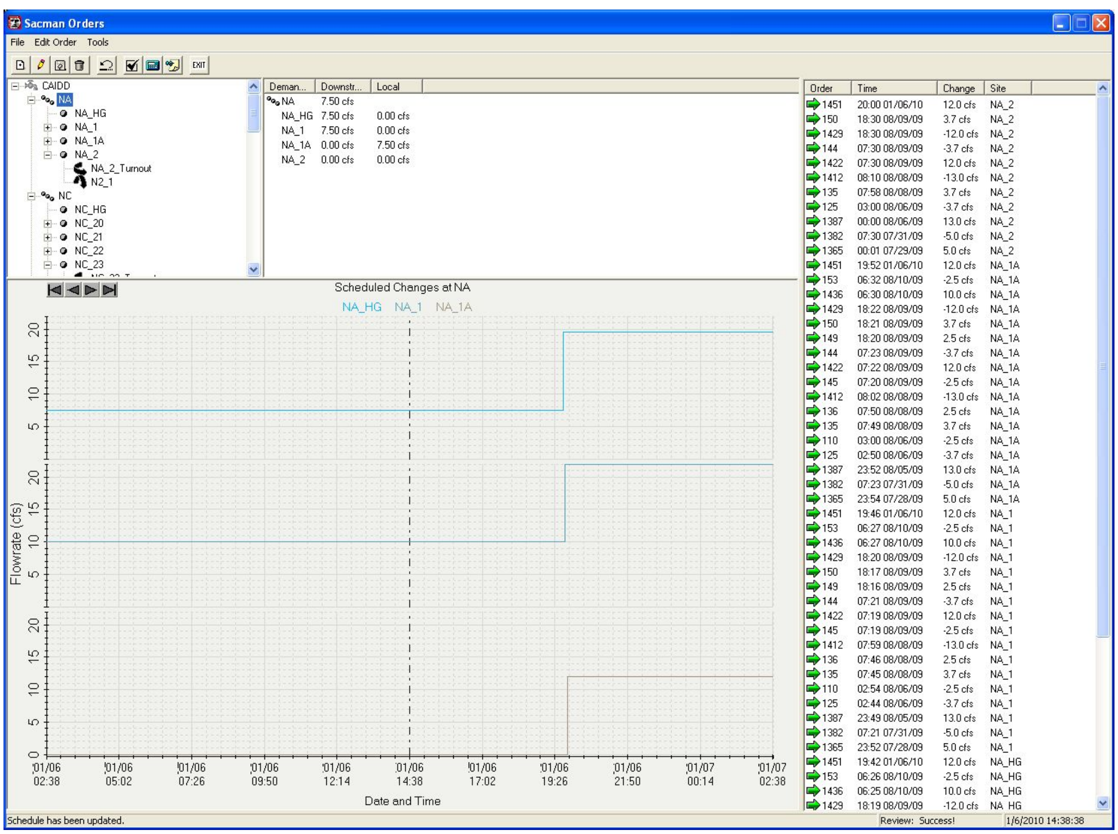


Figure 7. SacMan Order

Once the schedule is reviewed, the operator can post the schedule to the SacMan Control Program (CP)

SacMan CP (Figure 8) provides a user interface to configure the control implementation. It allows the operator to determine which canals or individual sites are under automatic control and the type of control applied. Additionally, it maintains a real-time event queue consisting of 5 types of events (in priority order):

1) System Diagnostics (Observers)
2) SCADA data reads
3) Central feedback control calculations – DDLC
4) Feedforward modifications to flow setpoints (Usually from SacMan Order)
5) Local control calculations – LULC, LFC

The queue uses a multi-threaded approach to minimize impact on computer resources while waiting for the time to execute the next event.

Both SacMan CP and SacMan Order utilize proprietary iFix libraries to communicate directly with the iFix process database. Both programs have been developed with the flexibility to connect to other data sources.

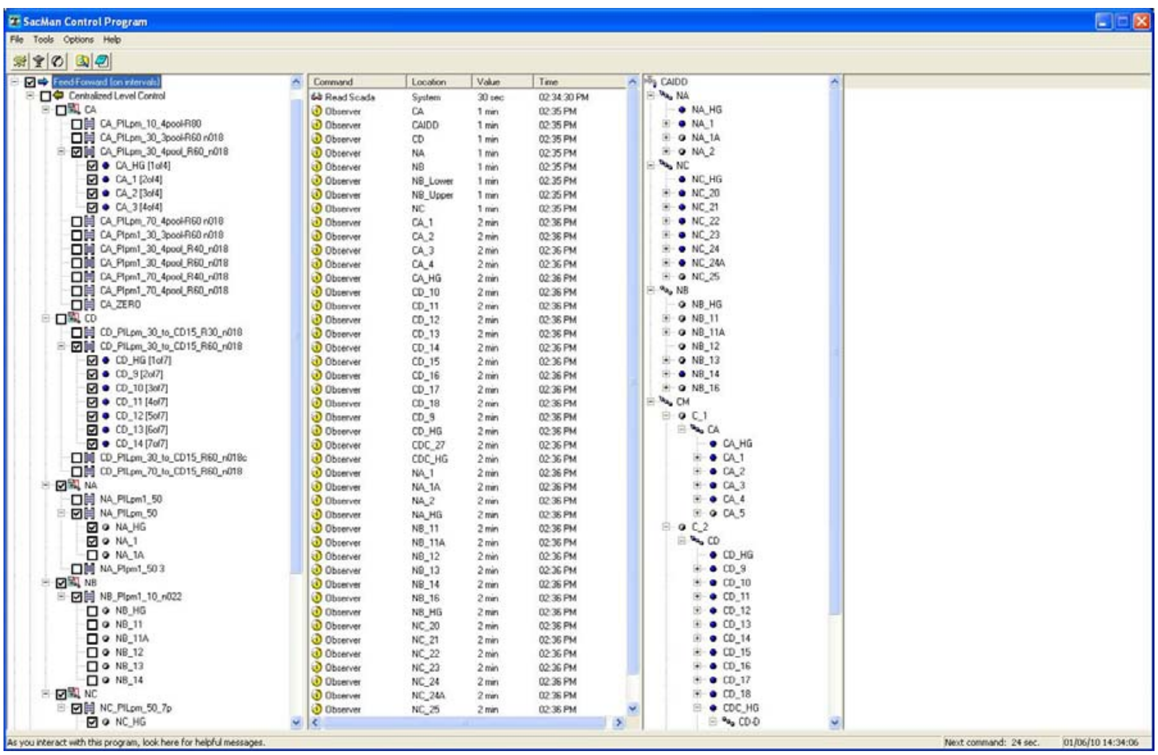


Figure 8. SacMan CP

The program provides the option of allowing the operator to approve both flow setpoint changes prescribed by the downstream level control as well as gate movements calculated from the local level & flow control events. After a set delay, the changes are automatically approved. Additionally, SacMan CP provides an option for sound cues to the operator to warn of large flow changes and gate movements.

Implementation at CAIDD

The North region of CAIDD presents an interesting management scenario. CAIDD controls the lateral canals, while the Santa Rosa Canal, which supplies the CAIDD canals, is managed by MSIDD. The first two pools of the Santa Rosa Canal are very large, and provide a great storage buffer. At times, MSIDD takes advantage of this situation, disrupting the flows into the NA, NB, and NC laterals of CAIDD by either quickly raising or lowering the water levels in the Santa Rosa pools. With the installation of gate position sensors, it was possible to begin automatic control implementation on the North side of the district with the hopes of providing constant flow to the laterals and better customer service to the growers. Automatic control has also been implemented on the CA and CD laterals of the Central region of CAIDD.

For routine use at CAIDD, SacMan is installed on an iFix SCADA View node (Figure 9). This allows automatic control to be implemented without competing with dispatch personnel for the SCADA computer. While some laterals are being controlled automatically by SacMan, CAIDD dispatchers can continue supervisory control on the rest of the district. The iFix View node automatically routes data exchange between SacMan and the iFix process database on the SCADA node over the district LAN using proprietary TCP/IP-based communication. From SacMan's point of view, this interaction is seamless.

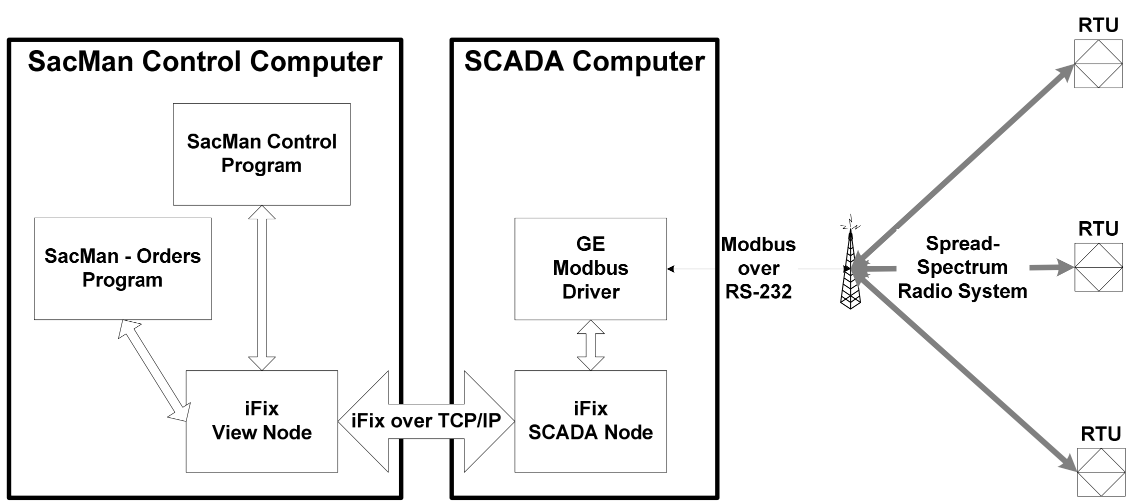


Figure 9. SacMan Implementation at CAIDD

A typical day starts by verifying the day's orders for the canals that are currently under automatic control. Care must be taken to ensure that the automatic routing will result in a realistic schedule for each operator. Once verified, the feedforward schedule is posted from SacMan Order to SacMan CP. Throughout the day, growers call the dispatch office to slightly modify their orders. Usually, these calls are placed far enough in advance to allow the feedforward schedule to be updated. When in operation, the automatic control manages the water levels quite well. As an example, Figure 10 shows the water level deviations in the NC lateral for 14 days starting 1 August 2009. The automatic control was engaged from the evening of 6 August through mid-afternoon on 11 August. The canal was under supervisory control for the remainder of the time.

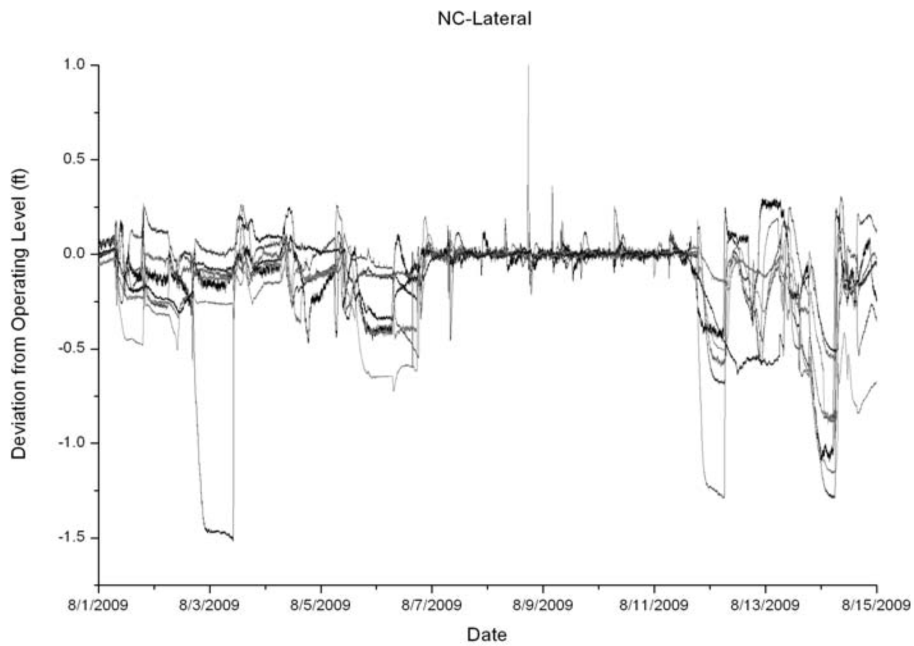


Figure 10. Feedback Control Performance on NC-Lateral

FUTURE WORK

From a supervisory control standpoint, CAIDD has found position sensor based gate movement to be superior to the original time-based movement. This is primarily due to fact that the gate position sensor compensates for the hysteresis in the motor when changing movement direction. They will continue to install gate position sensors as funding is available.

With automatic control implemented on the three north region laterals and CA & CD laterals in the central region, the focus moves to the Central Main Canal. The combined flow capacity of the CF and CG laterals is 450 cfs. The concern is that implementing automatic control on these laterals with the CMC still under supervisory control could result in large unexpected water level deviations in the CMC.

Initially, local flow control will be implemented on the rest of the lateral head gates on the CMC system. Automatic control will be extended down the remaining CMC laterals as funding allows for the installation of gate position sensors.

To this point, the state-space formulation of the feedback control has assumed complete control of the canal inflow. As noted earlier, the inflow to the CMC generally changes only twice each day. A new formulation has been developed that spreads flow mismatches across the pools of the canal. Should inflow not match demand, this control would spread this mismatch across all pools by equalizing the pool water level errors. Details of this control approach are discussed in a companion paper. Preliminary real-time testing will commence in the spring of 2010.

At this point, the automatic control is only in operation while ALARC staff is available. This is partially due to the fact that SacMan is still a research tool and continually being upgraded. The focus of the software development has been on proving the concepts of the ALARC automatic control approach and not on usability. User interface, control configuration, and startup issues will be addressed in the spring of 2010 to facilitate the integration of automatic control into routine district operations during the 2010 irrigation season.

The automatic control is most effective if it is allowed to run continuously. Up to this point, ALARC staff has monitored the automatic control on a 24 hr basis. To conform to current district staffing hours, an alternative "night mode" is under consideration. This would allow control on selected laterals to be limited to local flow control at the head gate, thereby limiting the number of sites running in an unsupervised fashion, but still maintaining some control on the system. Additionally, alarm monitoring software will be evaluated in 2010. This software will notify on-call personnel by phone, email, or text messaging should designated SCADA alarms appear. More robust alarm monitoring will also be added to SacMan.

REFERENCES

Bautista, E. and A. J. Clemmens. 2005. Volume compensation method for routing irrigation canal demand changes. *Journal of Irrigation and Drainage Engineering* 131(6):494-503.

Clemmens, A.J. and Strand, R.J. (2010a). "Application of Software for Automated Canal Management to the WM lateral canal." *J. Irrig. and Drain. Eng.,* (In Press)

Clemmens, A.J. and Strand, R.J. (2010b). "Downstream-water-level control test results on the WM lateral canal." *J. Irrig. and Drain. Eng.,* (In Press)

Clemmens, A.J. and Strand, R.J. (2010). "Distributing Flow Mismatches in Supply-Constrained Irrigation Canals through Feedback Control." *USCID Conference Proceedings: Water Management Conference March 2010, Sacramento, CA*, See Table of Contents for Page Numbers

Wylie, E. B. 1969. "Control of transient free surface flow." J. Hydraulics Div., Am. Soc. Civ. Eng. 95(1), 347–361.

DISTRIBUTING FLOW MISMATCHES IN SUPPLY-CONSTRAINED IRRIGATION CANALS THROUGH FEEDBACK CONTROL

Albert J. Clemmens, P.E. PhD[1]
Robert J. Strand[2]

ABSTRACT

The operation of main irrigation canals is complicated in situations where the operator does not have full control over the canal inflow, or where there are very long transmission distances from the point of supply, or both. Experienced operators are able to control the canal, but often supply errors are simply passed to downstream, thus creating problems further down the system. In previous work, the senior author showed that it is important to contain such errors and not let them pass downstream. With automatic upstream level control, all flow errors are passed to the downstream end of the canal. Distant downstream water level control requires full control of canal inflow. Without this, most errors will occur toward the upstream end of the canal. An alternative scheme is offered here where the canal check gates are controlled based on the relative water level error between adjacent pools. The scheme uses a simple linear model for canal pool response. The scheme is implemented as a multiple-input, multiple-output scheme and solved as a Linear Quadratic Regulator (LQR). Thus all gates respond to relative deviations from water-level set point. The scheme works to keep the relative deviations in all pools the same. If the canal has more inflow than outflow, the scheme will adjust gates so the water levels in all pools will rise together with the same deviation from set point. It thus distributes the error over the entire canal. When in equilibrium, operators will be able to judge the actual flow rate mismatch by the rate of change of these levels. The scheme acts like a combination of upstream level and distant downstream level control. It was tested on a simulation model of the Central Main Canal at the Central Arizona Irrigation and Drainage District, Eloy, AZ.

INTRODUCTION

Over the last several decades, irrigation districts have become more flexible in the service that they provide to users. Farmers need some level of flexibility in order to be efficient. This is particularly important where water is limited. However, irrigation districts are often constrained by their water supply infrastructure or by their water supplier. This hampers their ability to accommodate some requests by water users. Most districts require water users to request water ahead of time, so that they will have time to bring water to the site and arrange delivery. Order times are typically one to three days before the delivery is to begin. If the district stores water in a reservoir, it may take considerable time for the water to flow from the reservoir to the irrigated area. If the transmission time is more than a day and water order times are long, water users may feel constrained.

[1] Center Director, U.S. Arid Land Agricultural Research Center, USDA/ARS, 21881 N. Cardon Lane, Maricopa, AZ 85238 bert.clemmens@ars.usda.gov
[2] Electrical Engineer, U.S. Arid Land Agricultural Research Center, USDA/ARS, 21881 N. Cardon Lane, Maricopa, AZ 85238 bob.strand@ars.usda.gov

In addition, water users sometimes need to change their water orders to deal with unforeseen circumstances. Irrigated farming requires a lot of adaptation in order to be successful. Thus changes in water orders are common. Districts that receive water from a water conservancy district or similar water authority are also sometimes constrained in their ability to change water orders.

Some districts use small regulating reservoirs along their canals to deal with the mismatches that inevitably occur. Other districts operate with small spills at the downstream end. In this paper, we describe a new water level control technique that takes the mismatches in supply and demand and distributes them over all canal pools. As such, the method effectively uses the canal as a storage reservoir. The method was tested on the Central Main Canal of the Central Arizona Irrigation and Drainage District through unsteady-flow simulation. Tests on the actual canal were delayed beyond the date of this publication.

EXISTING CANAL CONTROL METHODS

A common method for controlling canal check gates is to use some form of water level control, with the assumption that if the water levels are correct, then turnout flows will be correct. With upstream control, a check gate is typically adjusted to bring the water level to the target water level. If the water level is too high, the check gate opening is increased to allow more flow to pass through the structure, and thus the water level decreases. If the water level is low, the gate opening is reduced, decreasing the flow downstream. Good canal control can be achieved with this method if the correct amount of flow is supplied to the head of the canal. The operator sets the turnout gate so that when the water level is at the target level, the correct flow will pass through the turnout gate. Then, the upstream controller will pass the correct flow downstream from each gate. Upstream controllers are generally considered SISO – Single Input-Single Output (one water level – one gate). If there is an error in the canal inflow or if any of the turnout gates are set wrong, all the errors will pass downstream to the last canal pool. The operator thus must wait until these errors accumulate downstream before a reasonable correction can be made upstream. Uncorrected, these errors with either cause the last user to receive too little flow or cause a canal spill. Even if the gates and flows are initially set correctly, flow can drift over time because of weed plugs, changes in backwater downstream from turnout gates, etc.

Downstream water level control is intended to avoid the problems caused by the mismatch between supply and demand. When a water level deviates from the target value, control signals are sent to upstream gates to either increase or decrease the flow. Downstream controllers are slow relative to upstream controllers since they have to wait for flow changes to travel the length of the each pool. Downstream controllers essentially require an unlimited water supply at the canal head gate. A comparison to manual operation will give an idea of the magnitude of these changes.

When a canal operator releases the flow from the canal head gate, it takes some time to travel downstream to the turnout, thus there is a delay between the head gate flow change and the turnout flow change. Operators learn this timing through experience. The flow change times the delay time represents an additional volume that is added to the canal. Suppose a sudden change in the turnout flow occurs prior to a flow change at the head gate. If the operator immediately changes the head gate flow in response, it will be too late to accommodate the initial change in flow at the turnout. The canal water levels will change. To account for this delayed response at the head gate, the operator may make a larger flow change to account for this volume. So for example, if the turnout suddenly decreases by 10 cfs, the operator may decrease the inflow to the canal by 15 cfs for a while, and then change back to the 10 cfs decrease to match flow rates.

Feedback controllers respond in the same way, although they don't know what changes occurred. They only know that the water level deviated. Thus feedback controllers often makes larger flow changes at the canal head gate than the change in flow downstream because or the delay time and volume change in the pool. Even though this occurs for a short time, such flow changes may not be acceptable, or even feasible.

CONTROL BASED ON DIFFERENCES IN WATER LEVEL ERRORS

With automatic upstream water-level control, a check gate is controlled based on the water level just upstream. With automatic downstream level water level control, a check gate is adjusted based on the water level at the downstream end of the next pool downstream, or upstream from the next check gate downstream. Control actions are based on the water level error, e_j;

$$e_j = y_j - SP_j \tag{1}$$

where y_j is actual water level, SP_j, the water level set-point and where j identifies the check gate.

In the approach proposed here, control actions are based on the difference in water level error, D_j;

$$D_j = e_j - e_{j+1} \tag{2}$$

where for example if j=1, the control of check gate 1 is based on the water level just upstream from check gate 1 minus the water level error just upstream from check gate 2. Thus this represents a combination of upstream and downstream control. This controller differs from these two methods in an important way. If for example, the water levels in both pools are say 0.1 ft above the set point, this controller takes no action since $D_j = 0$.

For upstream control, if we have 7 canal pools, we can control 7 gates; excluding the head gate, but including the furthest downstream gate. For downstream control, we also can control 7 gates, but including the head gate and excluding the most downstream gate. For this difference controller, we would only have 6 water level differences. Thus we control only 6 gates; excluding both the head gate and the most downstream gate. The net result is that this controller does not influence the inflow to the canal and it does not influence the turnout flows or spills. A diagram of this controller is shown in Figure 1. Instead, it adjusts the internal check gates to provide equal water level deviations for all pool, thus using the canal as a reservoir to mitigate inflow/outflow mismatches. It is recognized that this can only be done on a temporary basis. If the inflow and outflow are a

b

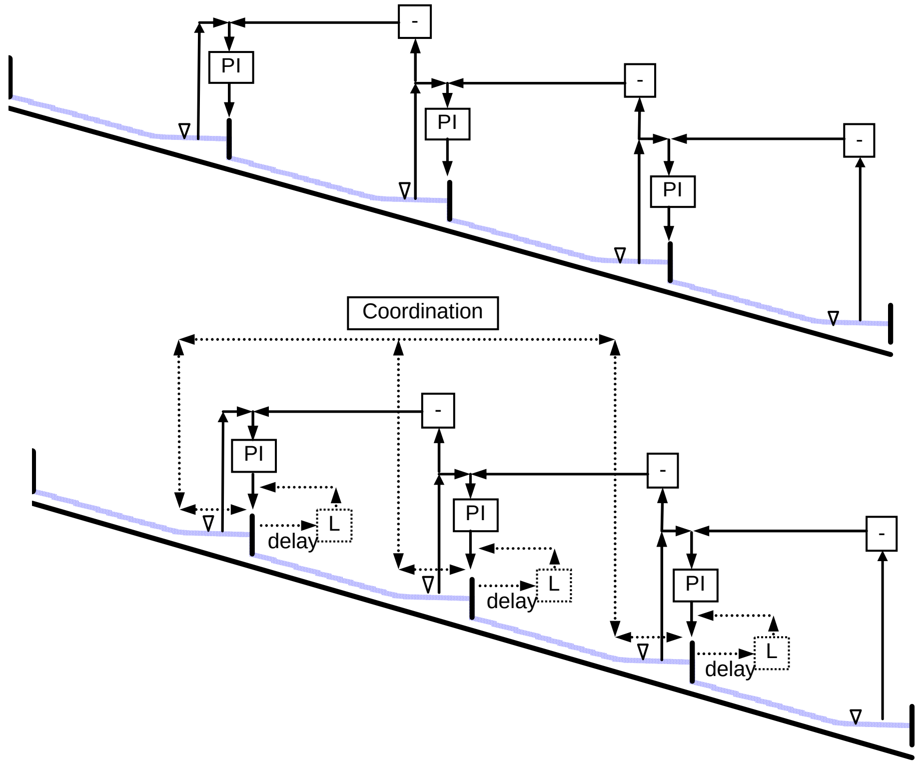


Figure 1. Schematic of Difference Controller, with varying levels of detail: a) simple PI, b) fully centralized.

roughly the same, the water levels in all pools will eventually stabilize at some level, likely close to the set points, but perhaps a bit off. If the inflow is greater than the outflow, all water levels will increase at a constant rate based the size of the flow mismatch and the backwater area upstream from each pool. If the inflow is too low, the water levels will drop at a more or less constant rate. The operator must eventually intercede to either increase or decrease the canal inflow or the demands, otherwise the canal will overtop or turnout flow will eventually decrease due to inadequate head.

MODEL FORMULATION

The canal response is described by a state-space model, where the Integrator-Delay (ID) model is used to describe canal pool response (Schuurmans et al 1999). The ID model is a simple linear model with a time delay that relates the water level to changes in the upstream and downstream gate flow.

$$y_j(t) = y_j(0) - \frac{tQ_j}{A_j} \qquad t \le \tau_k$$

$$y_j(t) = y_j(0) + \frac{(t-\tau_j)Q_{j-1}}{A_j} - \frac{tQ_j}{A_j} \qquad t > \tau_k \qquad (3)$$

where Q_j is a change in flow rate at gate j (i.e., the gate just downstream from y_j), t is time, τ_j is delay time in pool j, and A_j is the backwater surface area of pool j. (Note that we can replace y_j with e_j since the set point would be subtracted from both sides of Eq. 3.) Applying the ID model to the difference in water level error gives:

$$D_j(t) = D_j(0) - \frac{tQ_j}{A_j} + \frac{tQ_{j+1}}{A_{j+1}} \qquad \text{t} \le \tau$$

$$D_j(t) = D_j(0) + \frac{(t-\tau_j)Q_{j-1}}{A_j} - \frac{tQ_j}{A_j} - \frac{(t-\tau_{j+1})Q_j}{A_{j+1}} + -\frac{tQ_{j+1}}{A_{j+1}} \qquad \text{t} > \tau \tag{4}$$

where the terms with (t-τ) are only included when positive. Eq. (4) is discretized over a time step Δt with the following procedure, in which the water level response to prior flow changes is distributed proportionately among prior flow changes at discrete intervals, k.

$$\tau = 0 \qquad \frac{(t-\tau_j)Q_{j-1}}{A_j} = \frac{\Delta t}{A_j} Q_{j-1}(k)$$

$$0 < \tau < \Delta t \qquad \frac{(t-\tau_j)Q_{j-1}}{A_j} = \frac{\Delta t}{A_k}[Q_{k-1}(k)\frac{(\Delta t - \tau)}{\Delta t} + Q_{k-1}(k-1)\frac{\tau}{\Delta t}] \tag{5}$$

$$\Delta t < \tau < 2\Delta t \qquad \frac{(t-\tau_j)Q_{j-1}}{A_j} = \frac{\Delta t}{A_k}[Q_{k-1}(k-1)\frac{(2\Delta t - \tau)}{\Delta t} + Q_{k-1}(k-2)\frac{(\tau - \Delta t)}{\Delta t}]$$

…

For example if the delay time is 0.3 times the time step, then 70% of the response is attributed to current time step and 30% is attributed to the previous time step. This method allows us to account for past control actions even when the delay is much longer than the time step of the controller.

Here we use the LQR method as described by Clemmens and Schuurmans (2004), which uses a state-feedback control with a control law of the form

$$\mathbf{Q}(k) = - \mathbf{K}\,\mathbf{x}(k) \tag{6}$$

where $\mathbf{Q}(k)$ is the vector of control actions at time k (one element of the vector for each control structure or gate), $\mathbf{K}$ is the controller gain matrix, and $\mathbf{x}(k)$ is the vector of states at time k. Here the control actions are changes in gate flow rates. A separate flow controller is used to adjust the gate position to provide the correct flow rate, which provides a master-slave control scenario.

Values of the gain matrix, $\mathbf{K}$, are determined by minimizing the penalty function, J:

$$J = \sum_{k=0}^{\infty} \mathbf{D}(k)^T \mathbf{S}\mathbf{D}(k) + \mathbf{Q}(k)^T \mathbf{R}\mathbf{Q}(k) \tag{7}$$

where $\mathbf{D}(k)$ is the vector of water level errors at time k, $\mathbf{S}$ is the penalty function for water level errors (usually an identity matrix), and $\mathbf{R}$ is the penalty function for control actions (only main diagonal elements are non zero). Standard control engineering solutions are available for computing the gain matrix $\mathbf{K}$ that minimizes J, subject to the state transition equations (Schuurmans 1997). The result is a multiple-input multiple-output (MIMO) Proportional-Integral (PI) controller where all water level errors (and some prior changes in structure flow rates) influence the recommended changes to all structure flow rates, $\mathbf{Q}(k)$.

Eq. 4, with the discretization shown in Eq. 5, is put into state space form

$$\mathbf{x}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{B}\mathbf{Q}(k)$$
$$\mathbf{D}(k) = \mathbf{C}\mathbf{x}(k) \tag{8}$$

In this formulation, the state vector is in incremental form such that it includes changes in water level difference, ΔD_j; prior control actions, Q_j(k); and prior water level differences, D_j.

$$x(k+1) = [\Delta D_1(k+1) \\ Q_1(k) \\ \ldots \\ Q_1(k-n_2) \\ \Delta D_2(k+1) \\ Q_2(k) \\ \ldots \\ Q_2(k-n_3) \\ \ldots \text{for all pools} \\ D_1(k) \\ D_2(k) \\ \ldots \text{for all pools}] \tag{9}$$

where $\Delta D_j(k+1) = D_j(k+1)-D_j(k)$ and the number of prior control actions at gate j depends on the number of delays in the next pool downstream, pool j+1. Values of **K** multiplied by ΔD terms give the proportional action and by D terms give the integral action. Values of **K** multiplied by the prior control actions allows control based on lag-time predictions (e.g., as in the Smith Predictor of Deltour and Sanfilippo 1998).

If all water levels are of equal importance, **S** is represented as an identity matrix. Values of **R** are used to tune the controller, and reflect the relative importance of water level errors and gate flow changes in Eq. (7). Here the values for the diagonal elements are adjusted according to the square of the flow rate capacity of the pool downstream. The intent is that a 1 cfs change in a 100 cfs canal should have the same penalty as a 2 cfs change in a 200 cfs canal. (See Clemmens and Schuurmans 2004 for details).

The ID model is only appropriate for canal pools where a portion of the flow is under normal depth. For pools with backwater, one must also consider reflections waves. For a simple pool under backwater, the response of the canal is influenced by the backwater surface area, A_s and the resonant frequency. However, for pools with intermediate structures, such as culverts, there can also be a delay time due to the backwater that occurs upstream from these structures. The resonant frequency depends on the locations of the structures. For upstream control, the resonant frequency can be estimated from the speed of the celerity wave from the check gate to the next structure upstream, where the celerity, $c = (gD)^{1/2}$, where D is the hydraulic depth and g is the acceleration of gravity. This frequency often dominates.

Schuurmans (1997) recommends a linear filter of the form

$$D_{Fj}(k+1) = FD_{Fj}(k) + (1-F)D_j(k+1) \tag{10}$$

where D_{Fj} is the filtered value used for control and D_j is the measured value from Eq. 2. The filter time constant, T_f, is found from (Schuurmans 1996)

$$T_f = \sqrt{\frac{A_s R_p}{\omega_r}} \tag{11}$$

where R_p is the resonance peak height and ω_r is the resonant frequency ($1/P_u$, P_u = resonance period). The filter constant is then found from:

$$F_c = e^{-T_s/T_f} \tag{12}$$

where T_s is the sample time interval. Schuurmans (1996) recommends $T_s < 0.3\ T_f$. The time delay caused by the filter can be estimated from:

$$t_{delay} = \frac{F_c}{1-F_c} T_s \tag{13}$$

Control can be improved with the use of feedforward actions. However, since inflow changes are not matched to demand changes, an alternative form of routing was devised. Since the concept is to store excess water among all pools, each known inflow or outflow is routed proportionately to all pools, based on their relative storage, as reflected by the backwater surface area. Volume compensation (Bautista and Clemmens 2005) is used to route each inflow and each outflow, individually. Here, the routing time delay is determined from

$$\Delta t_{VC} = \frac{\Delta V}{\Delta Q} \tag{14}$$

where ΔV is the volume change resulting from flow change ΔQ. The volume as a function of flow rate is found from

$$V = aQ^b + c \tag{15}$$

where a, b, and c are empirical constants. Values for these coefficient change with flow resistance (Manning n) and downstream water level.

EXAMPLE

The Central Main Canal at the Central Arizona Irrigation and Drainage District (CAIDD) is used to test the difference controller. Details of the canal are provided in Table 1. ID model properties were determined through unsteady flow simulation with Sobek (Sobek 2000). Step tests were used to determine delay times and backwater surface areas (Schuurmans et al 1999). Pools 3, 4, 5, and 6 have culverts that would influence resonance waves. Pools 1, 2, and 3 do not. The frequency of celerity waves was computed based on the entire pool length and based on the distance from the check gate to the closest culvert upstream. Then, a series of step changes in flow at those frequencies (rounded to nearest min.) were input to each pool (separately). The magnitude of the flow change was such that if flow was governed by the ID model it would cause a change in depth of ± 2 in (5 cm) [2 in = $\frac{1}{2} P_u\ \Delta Q / A_s$]. For the pools with culverts, the resonance peak height (maximum change in water level) was higher and well above the expected 2 inch deviation.

Table 1. Central Main Canal physical properties (CAIDD).
(Side slopes 1.5:1.0 Horizontal to vertical, Manning n = 0.015).
(Lengths and drops do not include all siphons. Total length 94,508 ft. total drop 27.7 ft)

	Capacity	Length*	slope	Bottom width	Depth	Drop*
Pool	cfs	ft	ft/ft	ft	ft	ft
1	900	17,119	0.00013	12	12.2	2.2
2	900	7,144	0.00013	12	12.2	0.9
3	900	7,234	0.00040	12	9.9	-5.6
4	900	17,039	0.00018	12	11.5	-3.3
5	600	20,057	0.00010	12	10.8	-1.6
6	350	14,907	0.00016	8	8.4	-3.2
7	170	10,091	0.00010	4	6.9	-1.6
	Total	93,591				-18.4

*From start of reach downstream from one check gate to canal bottom at next check downstream. So includes mid pool siphons, but not siphon or drop just downstream from check gates.

Table 2. Canal pool properties at 60% of capacity.
(2 minute observation interval, 10 minute control interval.)

	Backwater Surface Area	Area	Delay time	Water level set point	Resonance period	Resonance Peak Height	Filter constant (x/16)	Filter delay	Delay Terms
Pool	ac	%	min	ft	min	s/ft^2		min	
1	16.1	23	4.5	11.0	44	0.0029	14	14	-
2	7.4	11	0.5	11.0	18	0.0054	14	14	2
3	4.5	7	5.5	8.7	11	0.0032	13	8.7	2
4	13.9	20	10.5	9.5	16	0.0025	14	14	3
5	13.6	20	18	7.4	15	0.0047	14	14	4
6	7.7	11	12.5	7.2	11	0.0047	14	14	3
7	5.4	8	6	6.25	34	0.0051	14	14	2

Table 3. Coefficients for volume-discharge relationships, Manning n = 0.014.

	a	b	c
Pool	$ft^{3(1-b)}s^b$	-	ft^3
1	1.30	1.961	4,526,026
2	0.20	1.958	2,101,785
3	2.52	1.775	1,018,566
4	4.03	1.847	3,363,685
5	8.59	1.888	3,490,771
6	12.29	1.829	1,412,312
7	649.96	1.286	347,471

Table 4. Schedule of demand and supply changes for multiple change test.

	Initial Flow	Site of change	Flow change	Time
site	(cfs)		cfs	
CAP	459	CAP	25.8	6:00
CM-1	424	Pool 1	-17.7	10:00
CM-1	388	Pool 4	-17.7	11:00
CM-1	353	Pool 7	-17.7	12:00
CM-1	282	Pool 5	+7.1	15:00
CM-1	177	CAP	20.1	16:00
CM-1	88			
CM-1	71			

The resonant frequency was computed for each pool based on the length of the entire pool and the length of the downstream portion of the pool. The filter constants used in the many SCADA systems are express as $F = x/16$. We chose to observe water levels every two minutes. Eq. (12) was used to determine filter constants, which are shown in Table 2. The state space model (Eqs. 4, 5, 8, 9) used the sum of the pool and filter delay times. The feedback control interval was selected as 10 minutes, resulting in the number of response delays for the state vector, **x**, shown in Table 2. Eq. (6) was used to determine the gain matrix **K** based on minimizing **J** in Eq. (7) subject to the constraints in Eq. (8). (For these tests, only the fully centralized controller was studied, with full lag time prediction and upstream and downstream decoupling.) Steady flow simulation results were used to determine the constants relating volume to discharge for Eq. (15) with a Manning $n = 0.014$ (Table 3).

The intent for operation of the Central Main Canal is to have all lateral head gates under flow control such that all errors in flow settings must be absorbed by the main canal. Canal inflow is determined by water orders to the Central Arizona Water Conservancy District (CAP) which are made the previous day and not under control by CAIDD. The first set of tests was made with a simulation model of the canal with the unsteady-flow simulation software, Sobek (Sobek 2000). Prior to running a test of the controller, a steady-state condition was set up with a flow of 459 cfs (13 m^3/s) at the headgate, dropping to 71 cfs (2 m^3/s) at the downstream end, with laterals taking the flow in between, as shown in Table 4. Then at 10:00 outflow from the canal was increased by 10 cfs without a corresponding change in canal inflow. Three tests were run with extra outflow in one pool at a time in pools 1, 4 and 7. The full centralized difference controller was run for all tests with all lateral flows held constant. This should cause all canal pools to drop, eventually by a constant rate since the turnout structures are under flow control. The results are shown in Figures 2, 3 and 4.

In Figure 2, note the initial drop in the level in pool 1. However, the controller eventually brought it back in line with the other water levels. In Figure 3, the water level deviates in pool 4, but recovers a little more quickly. In Figure 4, the water level in pool 7 drops significantly before recovering. These results are reasonable since pool 4 has two neighboring pools from which is can get recovery; while pool 7 is at the end of the canal where the flow change is a much larger fraction of capacity, the downstream gate is not adjusted, and there is a significant delay time in changes from gate 6.

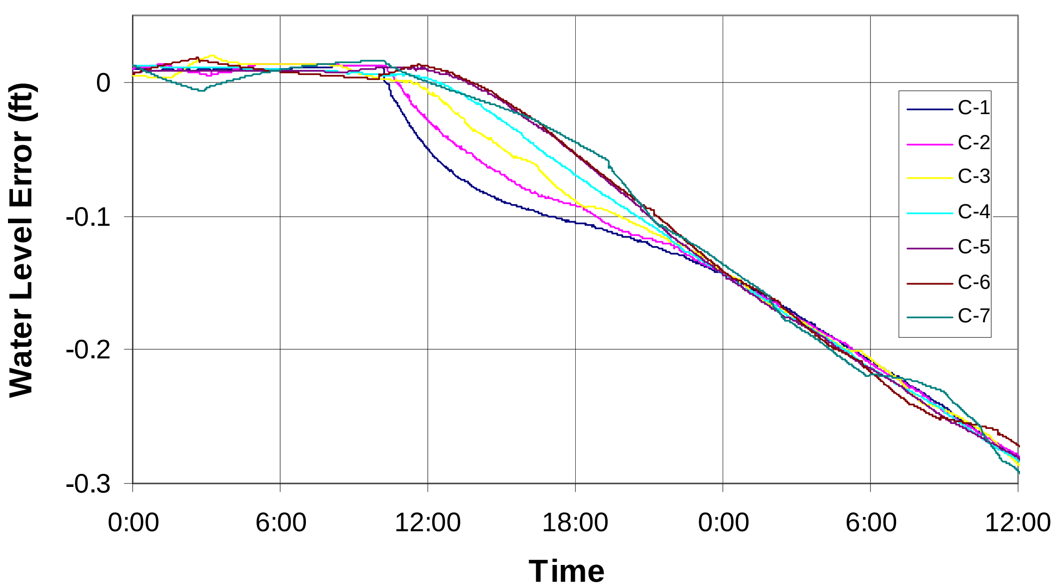


Figure 2. Water level errors for example problem with -10 cfs change in pool 1 (C-1).

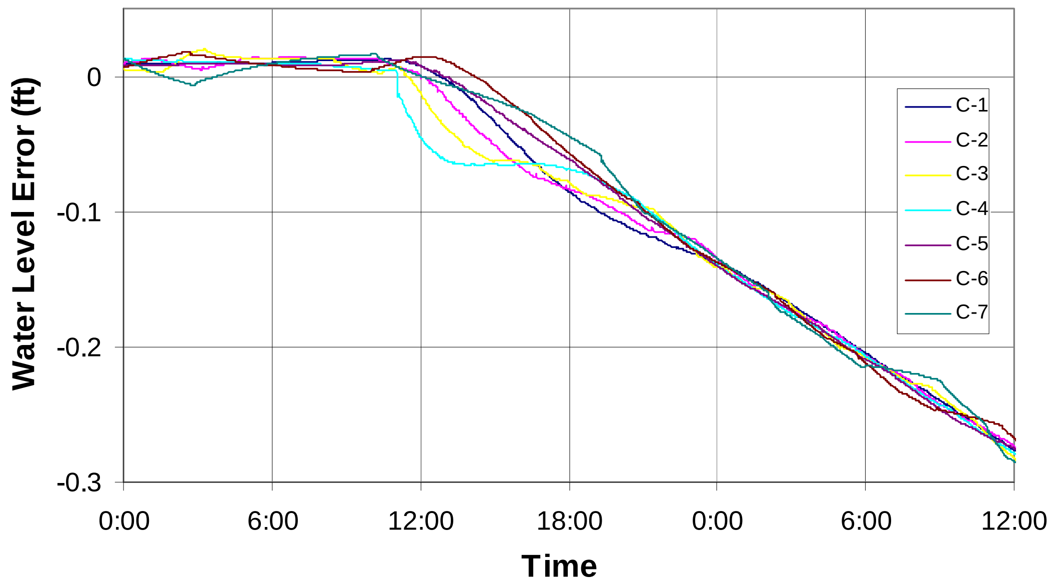


Figure 3. Water level errors for example problem with -10 cfs change in pool 4 (C-4).

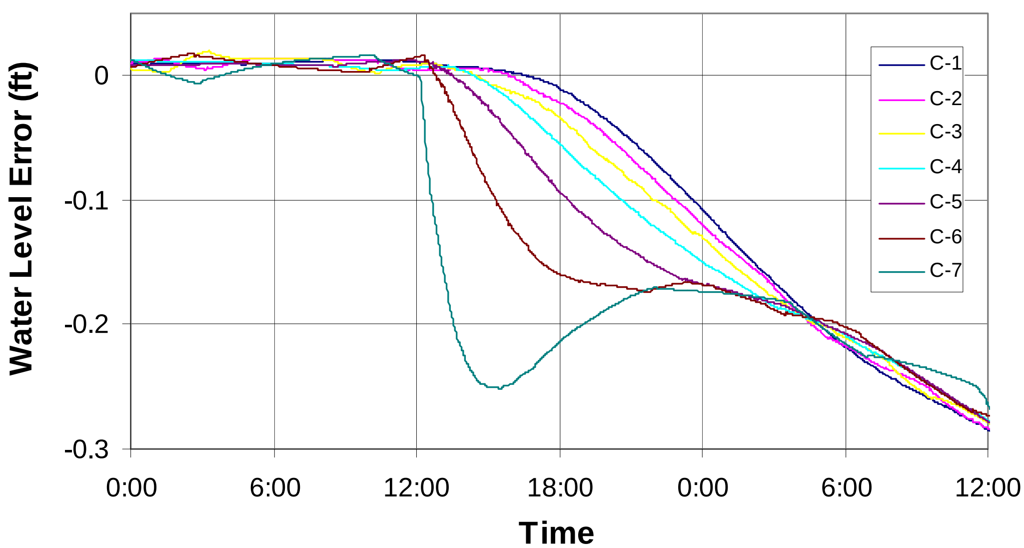


Figure 4. Water level errors for example problem with -10 cfs change in pool 7 (C-7).

The second test was meant to deal with the incompatibility between the water supply schedule and the schedule of water demands to laterals, and farmers downstream. Starting at the same initial condition, changes in the canal inflow and to the laterals for this test are shown in Table 4. Eq. 14 was used to determine the routing of flow changes to distribute each inflow or outflow to all pools. Table 5 shows the flow changes and how the flow change for each was distributed to the pools (negative pool flow is turnout increase). Note the bold time represents the scheduled change. These schedules were overlapped.

Table 5. Schedule of check gate changes for multiple change test.

	Q	Time	Q	Time	Q	Time	Q	Time	Q	Time	Q	Time
	(cfs)		(cfs)		(cfs)		(cfs)		(cfs)		(cfs)	
CAP	25.8	**6:00**									20.1	**16:00**
CM-1	19.7	6:15	4.1	9:59	4.1	10:31	-13.5	**10:00**	-1.7	13:50	15.4	16:16
CM-2	16.9	6:17	6.1	10:01	6.1	10:33	-11.6	10:02	-2.4	13:52	13.2	16:18
CM-3	15.2	6:25	7.2	10:09	7.2	10:41	-10.4	10:09	-2.9	14:00	11.9	16:26
Cm-4	10.0	6:43	10.8	10:27	-6.8	**11:00**	-6.8	10:28	-4.3	14:18	7.8	16:44
CM-5	4.9	7:24	14.3	11:10	-3.3	11:42	-3.3	11:10	1.3	**15:00**	3.8	17:26
CM-6	2.0	7:51	16.3	11:38	-1.4	12:11	-1.4	11:38	0.6	15:28	1.6	17:54
CM-7		8:41		**12:00**								18:47

The results are shown in Figure 5. Note that from 6:00 to 11:00 supply exceeded demand such that all the water levels rose. After 12:00, demand was more than supply such that the water levels dropped. The last supply flow change at 16:00 matched the inflow to the outflow (values in Table 4 don't add due to round-off error). The final error in water levels results from a volume mismatch between inflow and outflow timing. Of importance is that all the water levels eventually tracked each other. The volume associated with the difference in levels at the end of this test represents roughly 25 cfs for 1 hour. The small size of Pool 7 causes more deviation in the water level there. This method provides a convenient method for overcoming the mismatch in timing between supply and demand, while at the same time providing reasonable water level control.

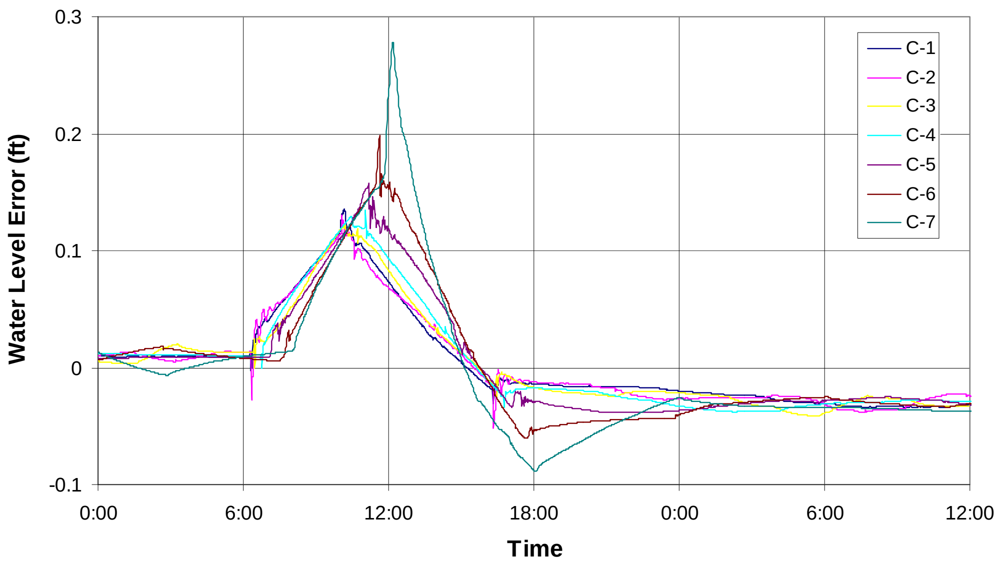


Figure 5. Water level errors for numerous, uncoordinated flow changes.

DISCUSSION

Control of water level differences among pools appears to be an effective way to deal with the complexities of main canal control. It allows an easy method to account for short-term demand/supply mismatches. It is a good mix of upstream control to maintain water levels and downstream control to avoid spills. Obviously this controller will not adjust supply and demand and will eventually lead to control failure. So it is up to the operator to work toward matching supply and demand through water supply ordering and interaction with water users. The intent of the method is to overcome the problem of distributing flow errors through the canal system, and instead concentrates them in the main canal.

It is possible to design these controllers as simple PI devices, so that they can be implemented with peer to peer communications between PLCs, but this has not been tested. It is also possible to put more weight on water level errors in some pools than others, thus avoiding deviations where pools have tighter constraints, but this method has also not been tested.

REFERENCES

Bautista, E. and Clemmens, A. J. 2005. Volume compensation method for routing irrigation canal demand changes. Journal of Irrigation and Drainage Engineering 131(6):494-503.

Clemmens, A. J. and J. Schuurmans. 2004. Simple optimal downstream feedback canal controllers: Theory. Journal of Irrigation and Drainage Engineering. 130(1), 26-34.

Deltour, J-L and F. Sanfillipo. 1998. Introduction of Smith predictor into dynamic regulation. Journal of Irrigation and Drainage Engineering. 124(1), 47-52.

MathWorks 2003 Matlab User Guide. The MathWorks, Inc., Natick, Massachusetts.

Schuurmans, J. 1997. Control of water levels in open channels. Ph.D.-dissertation Delft University of Technology, The Netherlands.

Schuurmans, J., A. J. Clemmens, S. Dijkstra, R. H. Ahmed, O. H. Bosgra, and R. Brouwer. 1999. Modeling of irrigation and drainage canals for controller design. Journal of Irrigation and Drainage Engineering 125(6), 338-344.

Sobek 2000 Manual and Technical Reference. WL|Delft Hydraulics, Delft, The Netherlands.

CREATING THE IDEAL COMMUNICATION NETWORK

Dan Paladino[1]

ABSTRACT

The internal expectations for irrigation water supply and other water providers are daunting today – especially with the economy and tighter credit markets. What are the current and future communications needs for your organization? What technologies are out there? Which technologies can be used together to create a reliable communication network? What happens if you make the wrong decision?

Numerous communication technologies have been introduced into the irrigation and water management market over the years all claiming to be the best and most reliable communication tool. How do you decide what is truly best for your situation? For your organization's future expansion? For the changing needs of your organization? Can you count on your technology partner to support its technology moving forward?

This session will help you navigate potential 'pitfalls' of creating your 'ideal' network within current challenging industry and financial obstacles. It also will help you take the next step as you both identify and select the ideal technology or technologies to meet 'your' needs, as well as provide direction in selecting a technology partner(s) that will make your job easier.

You will learn how you can combine existing infrastructure with new technology to create a robust and reliable communication network within the irrigation district and other related deployments.

INTRODUCTION AND BACKGROUND

There are many challenges that one will encounter when piecing together the ideal communication network. While many would have you believe that you can easily accomplish your communication goals with a single product, just remember one thing — you can't!

Historically many mistakes have been made due to lack of planning, insufficient research and of course the mother of all mistakes--poor decision-making. It is human nature to want to trust our colleagues, our neighbors, the nice sales person from the company you just learned about, or the reliable representative you've known for years. The first piece of advice is you will take the fall for a bad decision.

If you keep in mind the consequences of making a bad decision you are on the right track to creating the "Ideal Communication Network."

[1] Business Development Manager, FreeWave Technologies, 1880 S. Flatiron Court, Suite F, Boulder, CO, 80301, dpaladino@freewave.com

STEPS FOR SUCCESS

As with achieving any goal one must understand where they want to end up. If you want to end up with a communication network that doesn't meet your needs today or in the future then all you need to do is buy a few communication devices for a low price, install them in the field and let the good times roll! However if you want to build a communication network that meets both your current needs AND your long-term goals then take the time to build a communications strategy complete with tactics and measurable objectives.

The intent of this paper is to outline good processes and provide steps to assist you in deploying a communication network that can meet your objectives and needs for many years to come.

Step 1 – Identify Needs, Goals and Limitations

Without physically identifying your current needs, your future goals and your real or potential system limitations you will never be able to "create" the perfect communication network. In this first step consider the equipment or locations you want to communicate to or from. Understand what the future communication plan is. Will you be utilizing a high-speed backbone with complete need for IP addressability? Are you up to speed on internal or federal security standards? How often will you be required to refresh the data? Will you need data by exception or timed poll and response data? What type of equipment (PLC, RTU, other) will the communication device(s) be connected to? What type of data interface capability does the equipment have? What equipment will you be installing in the future? These are just a few of the initial questions you will need to address.

As a starting point, an important recommendation would be to speak with managers within your own organization and ask what efforts have been made to date on the communication front. Start with the IT department! Second, seek out a trusted source that has recently gone through the process. Take advantage of their planning successes and failures. Use their experience! Everybody wants to either show their new system, brag about their success, or at the very least help a friend or colleague.

Step 2 – Are There any Budgetary Concerns or Limitations?

Nothing derails a great plan quicker than lack of dollars. Just think about that vacation or new boat you always promise yourself.

Budget is always step two for a reason. After determining your needs, you better know what you're able to spend. This may be the most "fuzzy" area because so many costs are hidden in the actual roll-out and long-term support of a system.

Generally, during the purchase cycle you get a quote, justify the cost--sometimes at the expense of headcount--then you submit the request for budget approval and wait for the dollars to be distributed. Unfortunately, the cost of buying (budgeted capital dollars) is sometimes dwarfed by the cost of maintaining (operating budget) a system and/or keeping it running. Know the support available from both the seller and the manufacturer. This includes warranty and "promises." Remember, one day that nice salesperson may be moving on or the manufacturer that sold the equipment may be acquired and you don't want to have to buy what was promised as part of the deal. In addition, shipping and taxes will add to the total cost.

Step 3 – Know the Market and the Available Technologies

This is where the rubber meets the road. It's time to research all available options, to learn what is really available and what is going to be available in the future. Don't fall for the old "we are going to release it next year" routine. Buyer beware is a popular saying for a reason! Talk with colleagues within your organization. Attend association meetings and trade shows. Proactively contact manufacturers. Remember not all manufacturers know your specific situation and your needs. Just because a salesperson has not called you does not mean he doesn't have what's right for you. Today's communication products vary in every possible way. Each manufacturer or technology has advantages and disadvantages. Don't think because big dollars are spent advertising that the product being advertised is best for you. I remember a car manufacturer from Yugoslavia being advertised on TV and in publications. What happened to that car? My point is not that advertised products are bad, but more so that not all good products are advertised!

It is also very important to know and remember that not a single product--and likely not a single manufacturer--can meet all of your needs. This is why the process starts with Step 1 — identify needs, goals and limitations.

Investigate as many options as possible. Look at serial communication, Bluetooth, Ethernet, Microwave, landlines and cellular networks--anything that is available. Just be sure to learn the true limitations of each. These limitations will include cost (installed and on-going), reliability, technology obsolescence, capabilities and flexibility. Also learn the benefits of each. How has the product performed over the years? Does the manufacturer stand behind his product and deliver on his promises? Is this technology proven or is it end of life?

Next, as you will probably not deploy a brand new communication network all at once, learn how the products work between various generations from the same manufacturer. If, for example, a radio manufacturer is not compatible between past, current and future generations, you could be in trouble when you need to expand your network in three or four years.

Understand how you can combine technologies to meet your needs. If you need mobile access to your Supervisory Control and Data Acquisition (SCADA) network, find somebody that offers it. If you have a microwave tower place, use it. Piggy-back slower licensed radio networks with faster 902 to 928 megahertz (MHz) frequency hopping, AES encrypted networks. Know that you can install I/O capable radios (analog and digital signal, 4 to 20 and 1 to 5) to relay contact closures or other data without adding a new PLC or RTU. Technologies have advanced over the years, so toss out your old perceptions and learn how today's technology can work for you.

Step 4 – System Design, Deployment and Support

This is the step that can bring great planning, great research and legendary negotiating to its knees! Be prepared to preplan your installations by taking the extra step to have path-studies and network design models completed. Most reputable organizations will offer these services for little or no charge or will wave the fee if you buy their equipment. Generally you will work in cooperation with your suppliers to establish network expectations and gather GPS coordinates for entry into a computerized software program that can provide you with communication paths, fade margins, Fresnel zone, topographical mapping, etc. for your future network.

After reviewing the path-study and network design information, focus on preparing a detailed project plan. This plan should detail the installation stages prior to actual deployment. Have meetings with manufacturers, installers and anybody else involved in the project and don't forget to assign a project manager!

Interview and pre-qualify personnel for the actual installation. If the personnel are internal, require that they receive factory training prior to starting the install. If you don't have the staff, ask the vendor.

You've planned, selected the right technology and you have your installation strategy, so you're almost there. Only one minor, yet commonly overlooked detail remains. Accessories! Do not skimp on accessories! Coaxial, antenna, surge protection, band-pass filters and proper sealing against the elements are just a few accessories to consider. Nothing will derail a communication network quicker than the wrong coaxial, wrong antenna, bad connection or the desire to save a few dollars on surge protection.

Lastly, make sure that whoever sold you the equipment is as committed to its success as you are. It is not unreasonable to expect a dedicated technical contact(s) that is available to assist you by phone 24 hours a day, seven days a week, 365 days a year.

UTILIZING THESE STEPS FOR SUCCESS

This paper is meant to act as a template for assisting you in creating your ideal communication network. The utilization of the above steps or at least the concepts described within will dramatically increase the likelihood of creating a communication network that will meet the needs of your organization for years to come. Carefully studying and anticipating your network needs will help you determine what type of equipment you should invest in. Don't be coerced into being sold equipment or technology that works fine today but will be obsolete in just a few years. Knowing your real needs will allow you to strategically gather information, interview potential suitors and eliminate what is not right for you. It will also help prevent the financial mistake that could cost you the career you've worked so hard to build.

Be prepared to be shocked by what you learn. Know that you will find that a combination of many different technologies and manufacturers will likely be the right decision for your future system. Past beliefs will soon turn to misconceptions unless you take the time to research and select appropriately for your well-planned system. Share the responsibility of defining actual needs on what is most critical within your organization. Use references from your community and remember that your community might be the association member next door or a similar organization on the other side of the country.

As you move forward and have a greater understanding of your ideal network, you'll have greater confidence in making your selections, overseeing the project and getting what you want. This confidence is a direct result of having invested time into identifying your goals, understanding your network needs and having a firm grip on the technologies and equipment available to you, how they enhance one another and how they will serve you for years to come.

CONCLUSION

The perfect network can only be achieved by utilizing everything that is available. By employing the above steps, a "Hybrid" network can be created which not only meets the current needs but establishes a game plan for future growth. This future growth can and should be physical as well as spatial. It should meet your needs and the needs of your internal and external customers. Your communication network is a solution that considers budgetary constraints and technology advancements. It combines existing infrastructure with future hardware selection and deployment. It anticipates the unexpected and is prepared for reliable delivery, control of your resources and processes and the security to protect your critical infrastructure.

REFERENCE EVAPOTRANSPIRATION (ET_O) MAPS FOR CALIFORNIA

Bekele Temesgen, Ph.D.[1]
Kent Frame[2]

ABSTRACT

The California Irrigation Management Information System (CIMIS) manages over 130 active weather stations throughout the state. Archived data is also available for 75 additional stations that have been disconnected from the network. Most of these stations produce estimates of reference evapotranspiration (ETo) for the station location and their immediate surroundings. Because of California's diverse landmass and climate, however, many locations within the state lack a representative CIMIS station. Some counties, for example, do not have a CIMIS station at all and others have only one or two stations. As a result, there are significant spatial ETo data gaps. In an attempt to mitigate this problem, CIMIS initiated a project in 2003 to investigate the possibility of coupling remotely sensed satellite data with point measurements to generate spatially distributed ETo values.

In cooperation with the University of California Davis's Center for Spatial Technologies and Remote Sensing (UCD CSTARS), CIMIS developed a model that derives daily solar radiation from the visible band of the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES) and couples it with air temperature, relative humidity, and wind speed interpolated between point measurements from the CIMIS stations. Two interpolation methods, DayMet and Spline, are selected based on accuracy of results, code availability, and computational efficiency. Daily ETo values are calculated using the American Society of Civil Engineers version of the Penman-Monteith equation (ASCE-PM) at 2-km spatial resolution. The accuracy of the ETo estimate was tested using cross validation techniques and we are confident that this product will assist the people of California in saving water and energy.

INTRODUCTION

The California Irrigation Management Information System (CIMIS) is a program in the California Department of Water Resources (DWR), Division of Statewide Integrated Water Management, Water Use and Efficiency Branch, that manages a network of automated weather stations throughout California. Currently, there are over 130 active weather stations on the CIMIS network that collect and transfer data at prescheduled intervals to polling computers at the DWR headquarters. The polling computers reformat the raw data and import it to the database servers where the data will go through quality

---

[1] Corresponding Author. Staff Land and Water Use Scientist, California Irrigation Management Information System (CIMIS), Department of Water Resources, P.O. Box 942836, CA 94236. Email: temesgen@water.ca.gov.
[2] Senior Land and Water Use Scientist, California Irrigation Management Information System (CIMIS), Department of Water Resources, P.O. Box 942836, CA 94236. Email: kframe@water.ca.gov.

control processes and stored. There are also about 75 inactive CIMIS stations. Inactive stations are stations that have been removed from the network, for various reasons, but the archived data is still available.

CIMIS was developed by the California Department of Water Resources (DWR) and the University of California Davis (UCD) in 1982. DWR assumed management and operations of CIMIS in 1985 and has since been providing estimates of reference evapotranspiration (ETo) and measured weather parameters at the weather stations. ETo is evaporation plus transpiration from grass surfaces on which the CIMIS weather stations stand. CIMIS uses the modified Penman equation, further modified for conditions in California, to calculate ETo. CIMIS's version of the modified Penman equation is referred to as the CIMIS Penman equation in some literatures. CIMIS also provides ETo values calculated using the American Society of Civil Engineers (ASCE) version of the Penman-Monteith equation for interested users. Studies have shown that there are no significant differences between ETo values calculated by the CIMIS Penman and the ASCE version of the Penman-Monteith methods (Temesgen et al. 2005).

Although CIMIS is one of the largest agro-meteorological weather station networks in the world, the data from its stations represent only a small fraction of microclimates in the State, resulting in significant spatial data gaps. Recognizing this fact, CIMIS and the University of California Davis (UCD) remote sensing scientists have developed a model that couples remotely sensed satellite data with point measurements from the CIMIS stations to provide daily maps of ETo for the entire State.

Remote sensing has made remarkable advances in recent years enabling scientists to produce spatially distributed estimates of ETo and other products. The accuracies of these products, however, depend on the models used and atmospheric conditions at the time of data acquisition. The specific model that CIMIS and UCD developed derives solar radiation data from the Geostationary Operational Environmental Satellites (GOES) and interpolates other weather parameters measured at the CIMIS stations using data interpolation methods that depend on the density of ground stations. The more stations there are in a given area the more accurate the interpolated parameters will be. Two interpolation methods selected for this purpose are the Spline and DayMet methods. Brief descriptions of the methodology used will be presented in the following sections.

ETo Equation

The Penman-Monteith equation has been accepted by many researchers as a standard method for estimating ETo (Smith et al. 1991; Allen et al. 1998; Allen et al. 2000; Walter et al. 2000; Itenfisu et al. 2000; Howell et al. 2000). Therefore, CIMIS decided to use the ASCE version of the Penman-Monteith equation for estimating daily ETo values at 2-km spatial resolution for the entire state of California. The ASCE version of the Penman-Monteith equation for daily ETo calculations is given as:

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \frac{C_n}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d U_2)} \tag{1}$$

where ETo is reference evapotranspiration (mm d^{-1}), Rn is net radiation(MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), (e_s - e_a) is the vapor pressure deficit of the air (kPa), e_s is the saturation vapor pressure (kPa), and e_a is the actual vapor pressure (kPa), Δ is the slope of saturation vapor pressure-temperature curve (kPa $^oC^{-1}$), γ is the psychrometric constant (kPa $^oC^{-1}$), T is mean daily air temperature (^{o}C), C_n is the numerator constant for the reference type and calculation time step, C_d is a denominator constant for the reference type and calculation time step, U_2 is mean wind speed at 2-m height (m s^{-1}). For grass references, the ASCE Penman-Monteith has a C_n value of 900 and a constant C_d value of 0.34 for daily time steps.

The soil heat flux for a daily time step in Equation 1 is assumed zero. It has been established that this is a reasonable assumption since the fluxes entering and leaving the soil on a daily basis are about the same. The ASCE Penman-Monteith procedure for calculating Rn from measured weather parameters is (Allen et al., 1994, 1998):

$$Rn = (1 - \alpha)Rs - \sigma\left(\frac{T_{K\ max}^4 + T_{K\ min}^4}{2}\right)\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{Rs}{Rso} - 0.35\right) \tag{2}$$

where α = surface albedo, Rs = measured or estimated solar radiation (MJ $m^{-2}d^{-1}$), σ = Stefan-Boltzmann constant (4.901 x 10^{-9} MJ K^{-4} m^{-2} d^{-1}), $T_{K\ max}$ = maximum absolute daily air temperature (^{o}K), $T_{K\ min}$ = minimum absolute daily air temperature (^{o}K),e_a = actual vapor pressure (kPa), and Rso = clear sky solar radiation (MJ $m^{-2}d^{-1}$).

The solar radiation and surface albedo in Equation 2 were derived from the GOES data and will be described later. Saturated and actual vapor pressures in both Equations 1 and 2 were calculated using Tetens method as:

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \tag{3}$$

$$e^o(T) = 0.611 \exp\frac{(17.27T)}{T + 237.3} \tag{4}$$

$$e_a = 0.611 \exp\frac{(17.27T_{dew})}{T_{dew} + 237.3} \tag{5}$$

where e^o(T) is the saturation vapor pressure (kPa), T is air temperature (^{o}C), and Tdew is the dew point temperature (^{o}C).

The slope of saturation vapor pressure-temperature curve and psychrometric constant in Equation 1 are calculated using various empirical equations listed in Allen et al. (1994, 1998). The clear sky solar radiation is estimated using the Heliosat method. Heliosat is a European model that is designed to convert imagery acquired by the geostationary satellites into maps of solar radiation received at ground level (http://www.helioclim.net/heliosat/index.html). Maximum and minimum air temperature, dew point temperature, wind speed, and relative humidity values are estimated at each 2-km grid point using the two interpolation methods listed above and described below.

THE CIMIS-GOES MODEL

The model that is used to create daily maps of ETo and Rs is referred to as the CIMIS-GOES model in this document since it combines data collected by the CIMIS stations with data collected by the GOES. Figure 1, taken from Ustin et al. (2005) and Hart et al. (2009) , shows an overview of the steps involved in calculating ETo at each 2-km grid. The chart includes steps for the derivation of Rs from the GOES and interpolation of measured weather parameters from CIMIS stations.

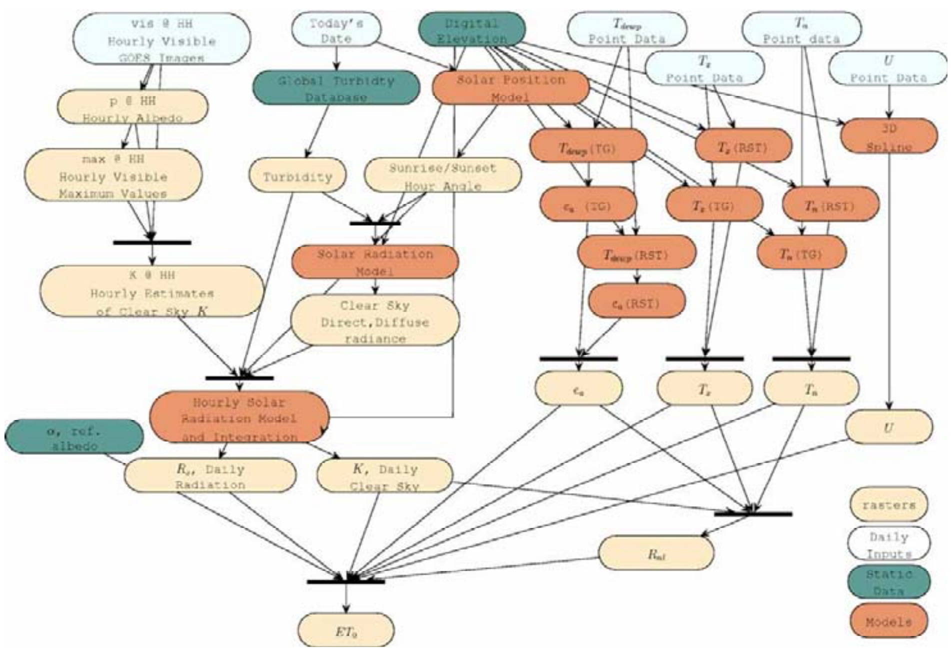


Figure 1. A chart showing the model used by CIMIS to map daily ETo values for the State of California.

Solar Radiation Model

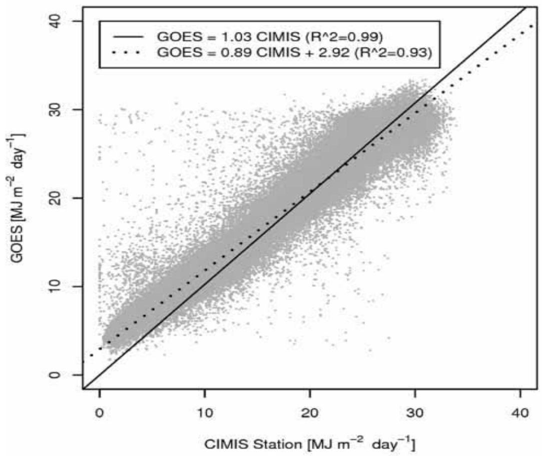
Solar radiation is the most important parameter in the calculation of ETo using the Penman-Monteith equation. Therefore, it is important that Rs estimates be as accurate as possible. The model that was chosen to derive Rs at each 2-km grid from the GOES data is the Heliosat II model. The model estimates Rs by combining model prediction of Rso with estimates of cloud index from the GOES imager visible channel data. Therefore, this method does not depend on measurements of Rs at the individual CIMIS stations. According to Hart et al. (2009), the clear sky solar radiation model used is part of the Heliosat-II program (Rigollier et al. 2000, 2001, Leferve et al. 2002).

The cloud index is estimated by comparing what is observed at the satellite sensor to what would have been observed if there was no cloud (Leferve et al., 2002). Ground surface and atmospheric (cloud) reflectance values needed to calculate the cloud index at each pixel are derived from time series of images. The assumption is that at some point in the time series the clouds are non-stationary and that the minimum value observed will provide estimates of ground reflectance and maximum value observed will provide cloud reflectance. The model then calculates clear sky index from the cloud index using empirical equations. The clear sky index, by definition, is the ratio of the observed radiation to the clear sky radiation. Therefore, solar radiation at each pixel is calculated by multiplying the clear sky index by the clear sky radiation.

For each location in California, the sunrise and sunset times are calculated daily. Within the sunlit period, GOES data are available for each hour. From each of the hourly GOES images, a clear sky index is calculated. This factor is assumed constant over the time intervals chosen. Clear sky solar radiation is also calculated for each of these intervals. The clear sky radiation and clear sky factor are used to calculate the actual radiation for each interval. Finally, the contributions from all intervals are summed to get the daily estimate of solar radiation.

The solar radiation model uses an analytical integration over solar angles and it is simple to change the frequency of the GOES cloud cover estimates. Therefore, missing cloud cover estimates, caused by lost GOES images, can easily be handled by extending the intervals adjacent to the missing time frames. The analytical integration assigns appropriate weights to the remaining cloud cover estimates. Atmospheric transmission in the model combines aspects of aerosols, relative humidity, ozone, and molecular scattering into a single parameter, the Linke turbidity (Ustin et al., 2005; Hart et al., 2009). The larger the Linke Turbidity, the larger will be the attenuation of the radiation by the clear sky atmosphere. Seasonal values of the Linke turbidity are derived from a world database of turbidity estimates (Remund *et al.* 2003).

Figure 4 shows comparison of the estimated and measured Rs values at all of the CIMIS stations from February 2003 through April 2006. Although there are some scatters, regression fits show a very good correlation between the two. It should also be noted that the measured Rs that is used in Figure 2 has not been assessed for potential measurement errors, which is not uncommon when dealing with such a large network. CIMIS is currently in the process of conducting analyses and expect to publish results in the near future.



(a) GOES vs. CIMIS R_{ns}

Figure 2. GOES estimated Rs versus Rs measured at individual CIMIS stations.

Data Interpolation

As stated above, daily maximum air temperature (Tx), daily minimum air temperature (Tn), average daily dew point temperature (Tdew), and average daily wind speed at 2 meters (U2) are derived by spatially interpolating point data from the CIMIS network. Spatial interpolation generates surfaces of continuous fields from data collected at discrete locations. A number of different interpolation methods, ranging from the simplest to the more sophisticated ones, were considered for this model. According to Hart el al. (2009), many researchers have indicated that simple methods can be used to interpolate climatic variables from dense and evenly distributed measurement sets (Philips and Marks 1996, Mardikis *et al.* 2005). However, when generating surfaces of weather data over California using CIMIS data, it is necessary to interpolate over large regions of complex terrain with sparse and unevenly distributed weather stations. Figure 3 shows the spatial distribution of the sparsely distributed CIMIS stations. As can be seen from the figure, areas in central valley have a dense distribution of stations whereas mountainous, urban, and desert regions are less represented. This distribution pattern is the result of CIMIS's original objective of serving California's agricultural growers irrigate efficiently.

It has been suggested that the incorporation of elevation improves interpolation results in cases where topography is an important factor for determining climatic variability (Daly *et al.* 1994, Thornton *et al.* 1997, Price *et al.* 2000). Figure 3a shows CIMIS station locations and groups them by elevation, with higher elevation stations having larger symbols.

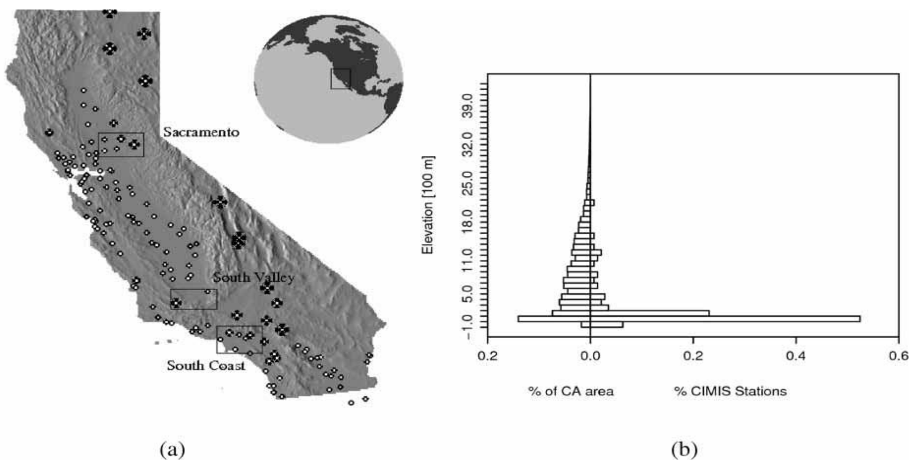


Figure 3. CIMIS weather stations. (a) Station locations, with larger symbols for higher elevations. (b) Histograms of elevations for California versus CIMIS stations.

Figure 3b shows the difference in the distribution and range of the elevation, comparing the CIMIS stations and California as a whole. Figure 3b clearly shows that mountain regions are under-represented. Taking all of these factors into consideration and based on computational efficiency, availability of codes, and accuracy of results, the Spline and DayMet methods were selected to interpolate the weather parameters measured at individual CIMIS stations.

Spline is an interpolation method that fits a surface through or near known points using a function with continuous derivatives. Two- and three-dimensional Splines were used based on which weather parameter is to be interpolated. Parameter values that control the properties of the interpolation function were selected using the cross-validation technique and visual observation of results. Cross-validation involves deliberately leaving out the measured parameter at one or more stations and comparing the model output to the measured value.

DayMet is an interpolation method that was developed at the University of Montana to generate daily surfaces of temperature, precipitation, humidity, and radiation over large regions of complex terrain (http://www.daymet.org/). It applies the spatial convolution of a truncated Gaussian (TG) filter with a set of observations and determines the weights associated with a given weather station for each point where weather parameters are to be determined, depending on the distance and density of the stations. The truncation and shape parameters for the DayMet model are determined by searching the parameter space and selecting the value that minimize the root mean squared error (RMSE) using the cross-validation method.

Maximum daily air temperature, minimum daily air temperature, and average daily dew point temperature from the CIMIS station sites were first normalized to represent values at sea-level. The data is normalized using a statewide average lapse rate adjustment of 5 ^{o}C/km for Tx, Tn, and Tdew. The normalized data was then interpolated using the twodimensional Regularized Spline with Tension (RST) and the DayMet methods. These temperatures were then adjusted for elevation using the lapse rate stated above. Because the CIMIS stations are not located in all geographic locations, both methods have some limitations in some areas of the State. Therefore, a decision was made to use an arithmetic average of values derived using both methods to create spatially distributed temperatures. Figure 4 shows average daily air temperature maps for a single day [June 18, 2005] created using this approach.

Relative humilities are measured at the CIMIS stations and the corresponding vapor pressures calculated by the datalogger. However, we decided to calculate both saturated and actual vapor pressures at each pixel from the interpolated temperatures to minimize the number of interpolated parameters and associated errors. Finally, the wind speed at 2-meters was interpolated using the three-dimensional RST method. It is worth mentioning that we found the wind speed interpolations to be the most unreliable since a single station with high wind speed values can cause anomalous effects. Therefore, we are working on improving wind speed estimation methods as we continue refining the entire CIMIS-GOES model.

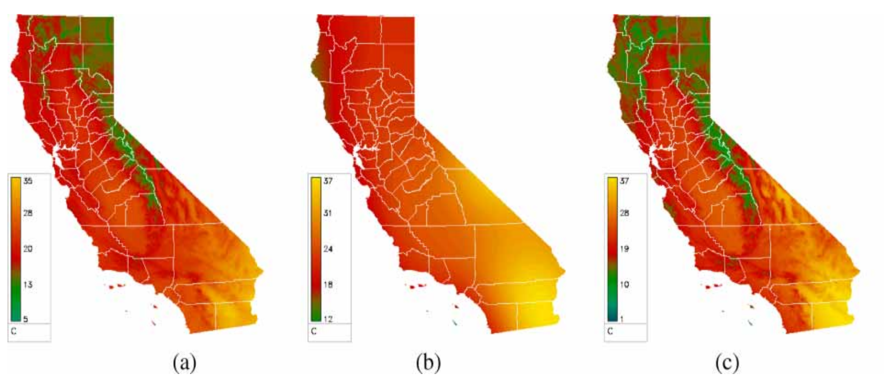


Figure 4. Results of air temperature interpolation using the different methods discussed above for June 18, 2005. (a) The DayMet method, (b) The 2-D Spline on the normalized values, and (c) the final approach with elevation correction.

REFERENCE EVAPOTRANSPIRATION

The final model output is reference evapotranspiration at each pixel. The daily ETo information is used for many purposes including irrigation scheduling and other water management practices. The accuracy of ETo values estimated from these methods depends on many factors. One such factor is the accuracy of the remotely sensed Rs data, which is in turn significantly affected by atmospheric conditions (e.g., cloudiness) and surface conditions (e.g., snow cover). Therefore, mountainous areas with snow cover and coastal areas with cloud and fog are more susceptible to errors.

Another important factor affecting the accuracy of ETo estimation by this model is the accuracy of the interpolation methods used. Interpolation methods in general are affected by the density of the weather stations and geographic features of the region. Since most of the CIMIS stations are concentrated in lowland agricultural areas, the mountains are again more susceptible to errors resulting from data interpolation due to the low density of weather stations. CIMIS is currently working on reducing these potential errors by refining the models. We believe that the ETo estimates provided using this method will be more accurate when compared to using data from a distant weather station with a different microclimate.

PUBLIC ACCESS TO THE DATA

After rigorously testing the product over an extended period of time, CIMIS released it to the public on September 9, 2009. Since then, we have received many positive comments from the public. We have also received information that the data is being used in water conservation programs by many water agencies. The daily ETo and Rs map is located at http://wwwcimis.water.ca.gov/cimis/cimiSatSpatialCimis.jsp. Figure 5 shows the view of the Spatial CIMIS tab and its associated links, such as Spatial Overview, Spatial Model, View Maps, and Map Reports. The Map Reports link is where users go to retrieve the data using an interactive Google Map Interface.

The Map Reports Help link on the Spatial CIMIS page provides detailed technical instructions for selecting locations, saving selections, scheduling automated email delivery, and generating reference evapotranspiration (ETo) and solar radiation (Rs) data reports at a 2-km spatial resolution from the Map Reports page.

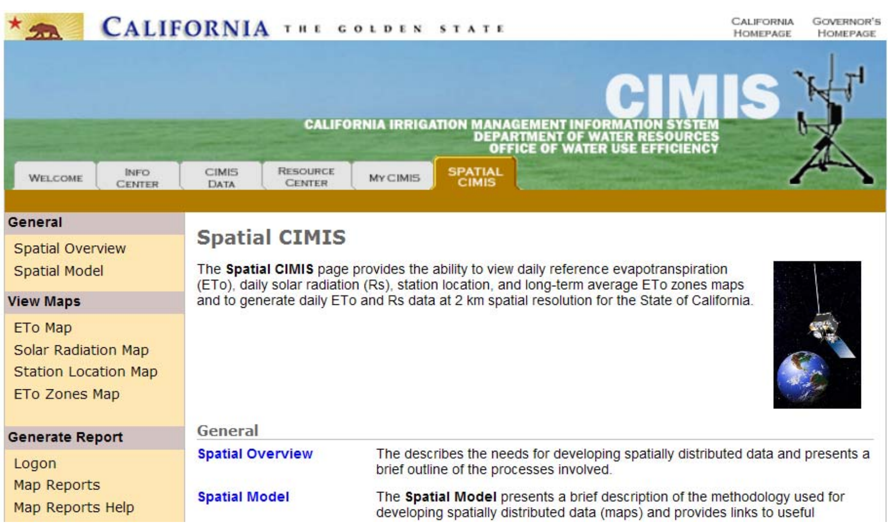


Figure 5. The newly released Spatial CIMIS tab assists users to view maps and retrieve data.

A point of interest can be selected using geographic coordinates, physical addresses, or zip codes. Coordinate selections can be specified by manually entering latitude and longitude values as an Address Search or by clicking points on the Google map interface. A maximum of 10 points can be selected at a time. The names and geographic coordinates of all selected points will display in the text boxes below the Google Map. These names can be replaced with new names that would help users to easily identify the points (example, alfalfa field, golf course, etc.). Plans are also underway to improve the features and make it more user-friendly.

Selections for the unit, date range, and data format for map reports are similar to the standard CIMIS data retrieval process. The user may specify the unit as English or Metric. The size of the data retrieved depends on the number of data points and the Date Range selected. Data can be generated in Web Report, CSV with Headers, and XML formats. Scheduling automated email deliveries will only be in CSV and XML formats.

After selecting data points, delivery methods, units, date range, and data format, users can click on the Submit button at the bottom of the page to generate the report interactively. Scheduled reports will be delivered via email after 6:00 a.m. Pacific Standard Time. The Save button has to be clicked to the selected specifications.

ACKNOWLEDGEMENTS

We would like to thank the University of California, Davis's Center for Spatial Technologies and Remote Sensing staff Quinn Hart, Susan Ustin, Marcela Brugnach, and Carlos Rueda for their contribution to the development of the CIMIS daily ETo map. We acknowledge the support by the California Department of Water Resources in providing resources for this project and Manucher Alemi, Chief, Water Use and Efficiency branch, for reviewing this article. We are grateful to Tom Hawkins, Scott Matyac, Richard Snyder, Kyaw Tha Paw U, Simon Eching, and Don Hatch for serving as advisory committee members for the CIMIS-GOES project.

REFERENCES

Allen, R. G., Smith, M., Perrier, A., and Pereira, L. S. (1994). "An update for the definition of reference evapotranspiration." *ICID Bulletin*, 43(2), 1-34.

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998). "Crop Evapotranspiration: Guidelines for computing crop water requirements." *Irrig. and Drain. Paper 56*, Food and Agriculture Organization of the United Nations, Rome, 300 pp.

Allen, R. G., Walter, I. A., Elliot, R., Mecham, B., Jensen, M. E., Itenfisu, D., Howell, T. A., Snyder, R., Brown, P., Eching, S., Spofford, T., Hattendorf, M., Cuenca, R. H., Wright, J. L., and Martin, D. (2000). "Issues, requirements and challenges in selecting and specifying a standardized ET equation." *Proc., 4th National Irrig. Symp.*, ASAE, Phoenix, AZ, 201-208.

Daly, C., Neilson, R.P., Phillips, D.L. (1994). A statistical topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology*, 33, 140–158.

Ellis, J., and Vonder Haar, T. (1976). *Zonal averaged ERB measurements from satellites for climate studies*. Technical Report Atmospheric Science Paper No. 240, Colorado State University, Ft. Collins, CO.

Hart, Q., Brugnach, M., Temesgen, B. Rueda, C., Ustin, S, and Frame, K. (2009). Daily reference evapotranspiration for California using satellite imagery and weather station measurement interpolation. *Civil Engineering and Environmental Systems*, 26 (1), 19-33.

Howell, T. A., Evett, S.R., Schneider, A. D., Dusek, D. A., and Copeland, K. S. (2000). "Irrigated fescue grass ET compared with calculated reference grass ET." *Proc., 4th National Irrig. Symp*., ASAE, Phoenix, AZ, 228-242.

Itenfisu, D., Elliott, R. L., Allen, R. G., and Walter, I. A. (2000). "Comparison of reference evapotranspiration calculations across a range of climates." *Proc., 4th National Irrig. Symp*., ASAE, Phoenix, AZ, 216-227.

Leferve, M., Aluisson, M., and Wald, L. (2002). *Description of the software Heliosat-II for the conversion of images acquired be Meteosat satellites in the visible band into maps of solar radiation available at ground level*. Technical report, Ecole Des Mines De Paris, November.

Mardikis, M.G., Kalivas, D.P., and Kollias, V.J. (2005). Comparison of interpolation methods for the prediction of reference evapotranspiration-an application in Greece. *Water Resources Management*, 19, 251–278.

Philips, D.L. and Marks, D. (1996). Spatial uncertainty analysis: propagation of interpolation errors in spatially distributed models. *Ecological Modeling*, 91, 213–229.

Remund, J., Wald L, Lefèvre M, Ranchin T, and Page J. (2003). Worldwide Linke turbidity information. *In*: *Proceedings of ISES solar world congress*, Göteborg, Sweden.

Rigollier, C., Bauer, O., and Wald, L. (2003). On the clear sky model of ESRA – European solar radiation atlas – with respect to the Heliosat method. *Solar Energy*, 68 (1), 33–48.

Rigollier, C., Lefèvre, M., and Wald, L., (2001). *The new method Heliosat-II*. Technical Report IST-1999-12245 D3.2, Report to the European Commission, April.

Smith, M., Allen, R. G., Monteith, J. L., Perrier, A., Pereira, L., and Segeren, A. (1991). "Report of the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements." Food and Agriculture Organization of the United Nations, Rome, 54 PP.

Temesgen, B., Eching, S., Davidoff, B., and Frame, K. (2005). "Comparison of some reference evapotranspiration equations for California" *J. Irrig. and Drain. Engr*., ASCE, 131(1), 72-84.

Thornton, P.E., Running, S.W., and White, M.A. (1997). Generating surfaces of daily meteorological variables over large regions of complex terrain. *Journal of Hydrology*, 190, 214–251.

Ustin, S., Hart, Q., and Brugnach. M. (2005). Calculation of daily reference evapotranspiration for California using GOES satellite measurements and CIMIS weather station interpolation, final report to California Department of Water Resources.

Walter, I. A., Allen, R. G., Elliot, R., Jensen, M. E., Itenfisu, D., Mecham, B., Howell, T. A., Snyder, R., Brown, P., Eching, S., Spofford, T., Hattendorf, M., Cuenca, R. H., Wright, J. L., and Martin, D. (2000). "ASCE's standardized reference evapotranspiration equation." Proc., *4th National Irrig. Symp*., ASAE, Phoenix, AZ, 209-215.

MONITORING NEAR REAL-TIME EVAPOTRANSPIRATION USING SEBAL®: AN OPERATION TOOL FOR WATER AGENCIES/GROWERS

Deepak Lal[1]
Byron Clark[1]
Bryan Thoreson[1]
Grant Davids[1]
Wim Bastiaanssen[1]

ABSTRACT

The Surface Energy Balance Algorithm for Land (SEBAL®) is used worldwide to estimate actual evpotranspiration (ET) at different spatial scales (individual fields to entire basins) and temporal scales (water year, growing season, individual day, etc.). SEBAL has been successfully applied on various surface types including crops, riparian, natural vegetation, playas, and wetlands. Comparisons of SEBAL actual ET results with reliable ground based measurements (Eddy covariance, Bowen ratio, lysimeter, water balance and scintillometer) have shown close agreement with differences ranging from 1 to 5% when compared to reliable ground-based estimates over a growing season when the model is applied by experienced operators.

This paper describes near real-time application of SEBAL® (Version 2009) to produce weekly maps of actual ET, crop coefficients, and biomass production for California's Central Valley. Each week, the maps for the prior week are produced and posted to the Internet. The maps are developed using MODIS multispectral satellite imagery with an end resolution of 250 meters. This paper discusses potential application of near real time actual ET maps by water managers, water supply agencies and irrigators.

INTRODUCTION

Accurate evapotranspiration (ET) estimates are necessary to quantify irrigation demands and support better utilization and management of existing water supplies. In California and other arid areas of the West, where fresh water supplies are limited and perhaps becoming scarcer, it is becoming more difficult to satisfy urban, environmental, and agricultural demands.

The Surface Energy Balance Algorithm for Land (SEBAL) is a widely used energy balance model that uses satellite based surface radiances coupled with ground based meteorological data to estimate evapotranspiration (ET) (Bastiaanssen et al., 2005). ET is the major component of the crop water requirement for agricultural areas and of the depletion of stored precipitation in non-agricultural areas.

SEBAL ET estimates have been compared with reliable ground-based ET estimates from methods including eddy covariance, Bowen ratio, scintillometer and water balance.

[1] SEBAL North America, Inc., 1772 Picasso Avenue, Suite E, Davis, CA 95618, www.sebal.us.

These validation studies have shown that SEBAL ET estimates agree with reliable ground-based estimates within 5% (estimated 95% confidence interval) across a series of monthly or more frequent images representing a growing season. Table 1 provides a summary of selected projects in California where SEBAL results were validated with reliable ground-based estimates.

Most of the information used by SEBAL is extracted from remotely-sensed satellite images. Additionally, local meteorological data is used when available. SEBAL is a cost effective way of monitoring ET over large areas. A study conducted in Idaho by Morse (2003) showed that the cost of monitoring water use with traditional methods in the eastern Snake River Plain was three to five times the cost of using the SEBAL energy balance model.

Table 1. Validations of SEBAL ET in California

Comparison Technique	Location	Duration	Crop	Difference	Reference
Surface Renewal	Sacramento Valley	7 months	Rice	5 %	Unpublished
Weighing Lysimeter	San Joaquin Valley	7 months	Peach	5%	Cassel (2006)
Weighing Lysimeter	San Joaquin Valley	7 months	Alfalfa	2%	Cassel (2006)
Water Balance	Imperial Irrigation District	12 months	Irrigated Agriculture	1%	Soppe et al (2006)

SEBAL is currently being applied to generate near-real time ET, crop coefficient, and biomass production estimates for California's Central Valley. The operational data products consist of spatially distributed grids of actual evapotranspiration, crop coefficients, and dry biomass production and are available on a weekly basis. A combination of satellite images from the MODIS Aqua and Terra satellites and a combination of ground-based observations and gridded weather data from the California Irrigation Management Information System (CIMIS) are used to produce these data.

This paper presents sample results and discusses the potential uses and applications of SEBAL as an operational tool to support water management.

METHODOLOGY

SEBAL Model

SEBAL (Version 2009) is culmination of more than 20 years of active research and has been applied successfully in fifteen countries over a variety of surface types. SEBAL utilizes an energy balance approach by partitioning the net solar radiation (R_n) available at the Earth's surface into its major consumers, including soil heat flux (G) and sensible heat flux (H), calculating latent heat flux (a measure of ET) as a residual term. A detailed explanation of the SEBAL model, its applications and validations can be found in Bastiaanssen et al. (2005). A brief conceptual summary is provided herein.

The net radiation flux (R_n) is estimated from the incoming solar radiation, accounting for incoming and outgoing shortwave and long wave components (both reflected and emitted). The soil heat flux is estimated as a function of R_n, surface temperature and Normalized Difference Vegetation Index (NDVI) that accounts for the effect of vegetation cover. The sensible heat flux (H) in SEBAL is estimated using a unique 'self-calibration' procedure. H is first estimated at two extremes ("hot" and "cold" pixels) and is then scaled between these two extreme temperatures for all pixels within the satellite image. The latent heat flux (LE), which is the amount of R_n consumed to vaporize available water as ET, is estimated as a residual of the energy balance based on the principle that energy can neither be created nor destroyed. The latent heat flux is converted into an equivalent depth of water consumed during the process of evapotranspiration using Equation 1:

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

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

The instantaneous ET_a is extrapolated to daily and longer periods by combining spatially distributed weather conditions from ground-based meteorological stations, evaporative fraction (Λ), and net available energy (R_n-G). Advection effects are estimated from average daily and periodic weather conditions and are incorporated in the ET_a estimates. The advection correction accounts for additional horizontal transfer of energy between pixels in the satellite image.

SEBAL Lumped Crop Coefficients

Crop coefficients are utilized to estimate crop ET and may be developed for other land surfaces as well. Most published crop coefficients assume stress-free conditions (optimal soil moisture levels, disease/pest free crops, etc.,) with no environmental and/or management related stresses; however, actual growing conditions often include such stresses that reduce ET from potential levels.

To a certain extent, published crop coefficients can be calibrated to represent actual growing conditions, but the process requires detailed field information. To overcome this difficulty, SEBAL utilizes actual ET to derive crop coefficients that represent actual field conditions (Equation 2).

$$K_{cs} = \frac{ET_a}{ET_o}, \qquad (2)$$

where K_{cs} is the actual crop coefficient, ET_o is the CIMIS reference ET and ET_a is the actual ET estimated by SEBAL.

SEBAL Biomass Module

Total dry biomass production is estimated as a function of photosynthetically active radiation (Monteith, 1972), light use efficiency (Field, et al., 1995) and normalized difference vegetation index (NDVI). Details of the formulation, application and validation of SEBAL biomass estimation can be found in Bastiaanssen and Ali (2003).

Photosynthetically active radiation (PAR) is the fraction of incoming solar radiation that can be potentially intercepted by a canopy and is estimated from incoming solar radiation Under actual conditions, only a fraction of PAR is absorbed by the canopy (APAR). APAR is estimated by accounting for the reflected portion of the radiation from the upper surface of the canopy and the fraction transmitted through the canopy based on total PAR and NDVI. The light use efficiency (ε) varies with c3 or c4 crops and is adjusted for environmental and/or management induced stresses based on estimated stresses from soil moisture deficit and ambient temperature. Moisture stress is estimated based on the evaporative fraction from SEBAL.

Input Data

A combination of satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS), meteorological data from CIMIS, and weather grids from the Coast-to-Mountain Environmental Transect (COMET) project are being utilized to develop the weekly SEBAL operational data products. Other data include a land use map from the National Agricultural Statistics Service (NASS) and a digital elevation model from the U.S. Geological Survey (USGS).

Satellite Images. SEBAL requires surface radiances in the visible, near-infrared and thermal bands of the electromagnetic spectrum. Surface radiances are estimated from satellite images acquired by the MODIS sensor on-board the Aqua and Terra satellites, which each have a one day return interval for a given area. A single MODIS image is selected each week to minimizing cloud cover and sensor zenith angle in order to maximize the area of coverage and the spatial precision of the results.

Weather Data. A combination of weather parameters from individual CIMIS stations and gridded weather data from COMET are utilized. A total of nine CIMIS stations (Table 2) located within the Central Valley are currently used to provide ground based weather data. These stations have been selected to achieve a reasonable representation of weather conditions for the Valley. Measurements utilized include relative humidity, wind speed, air temperature, and vapor pressure.

Gridded weather data utilized include dew point temperature, air temperature, wind speed, CIMIS reference ET, and K, a parameter describing the clearness of the sky.

Table 2. Selected CIMIS stations

ID	Station	County	Elevation (feet)	Latitude (Deg)	Longitude (Deg)
2	Five Points	Fresno	285	36.336	-120.113
6	Davis	Yolo	60	38.536	-121.775
15	Stratford	Kings	193	36.158	-119.850
30	Nicolaus	Sutter	32	38.871	-121.545
39	Parlier	Fresno	337	36.598	-119.503
56	Los Banos	Merced	95	37.009	-120.760
61	Orland	Glenn	198	39.692	-122.152
71	Modesto	Stanislaus	35	37.645	-121.188
145	Madera	Madera	230	37.018	-120.187
166	Lodi West	San Joaquin	25	38.130	-121.383
169	Porterville	Tulare	400	36.081	-119.092

Digital Elevation Model (DEM) and Land Use Map. The DEM is used to account for the effects of elevation, slope and aspect at each pixel on solar radiation and other factors and was obtained from USGS.

The land use map in SEBAL is used to estimate obstacle heights for land use classes within the study area. A land use map from developed by NASS for 2007 has been selected. The land use map has been generalized and resampled to 250 m spatial resolution to be consistent with the resolution of other input data.

RESULTS

Operational Data Products

The operational data products are available on the SNA website (www.sebal.us) in three formats: color coded maps, tables with summary statistics, and Google Earth overlays (Table 4). Raw data grids can also be made available to support hydrologic analyses. The color coded maps (.tif format) provide an overview of the spatial distribution of the data for each product. The spatial data from these individual operational products are summarized in a table format for the primary Hydrologic Regions (HRs) of the Valley: the Sacramento River HR, the San Joaquin River HR, and the Tulare Lake HR.

The Google Earth overlays provide color coded maps of the individual operational products that can be viewed in Google Earth. Google Earth overlays provide enhanced visualization of the spatial data and enable the user to view land surface of the areas of interest.

Table 4. Operational Products

No.	Product	Formats	Units
1	Actual ET	Map, Table, Google Earth Overlay	Inches/day
2	Total Dry Biomass Production	Map, Table, Google Earth Overlay	Pounds/acre/day
3	SEBAL Crop Coefficients	Map, Table, Google Earth Overlay	Unitless

Sample Results

The sample data selected for discussed herein represent two weeks in 2009: the period from 10/07 to 10/13 (Week 1) and the period from 10/14 to 10/20 (Week 2). Substantial rainfall occurred at the end of the Week 1 analysis period. Figure 1 presents the daily precipitation measurements for Weeks 1 and 2 for the selected CIMIS stations (Table 3).

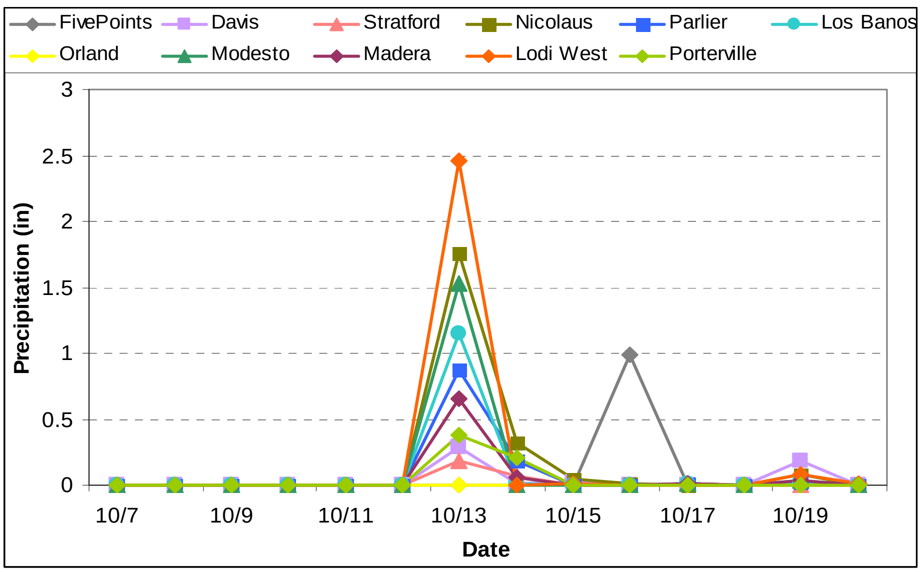


Figure 1. Precipitation Measured at the Selected CIMIS Stations

It is apparent from Figure 1 that the Valley, in general, received rainfall between 0.2 and 2.5 inched on 10/13/09, with no precipitation reported for the CIMIS stations at Five Points and Orland. In week 2 the CIMIS stations at Five Points and Davis reported precipitation of 1 and 0.25 inch, respectively.

Actual Evapotranspiration (ETa). Figure 2 provides color coded maps of spatially distributed average daily ETa (inches) for Weeks 1 and 2. Portions of the San Joaquin and Tulare Lake HRs for week 2 were obscured by the clouds; hence, ETa (including Kcs and Biomass) was not computed for those areas.

Although precipitation occurred on the last day of Week 1, its effects are not apparent in the Week 1 ETa map. ETa values estimated for Week 2 reflect the impact of precipitation on average daily ETa. The lack of an apparent rainfall effect in Week 1 is due to SEBAL ETa being estimated based on an image acquired prior to the rainfall occurring and then being extrapolated to the full week. The extrapolation is based on the assumption that the soil moisture and crop growing conditions on the day of image are representative of the entire period represented by the image.

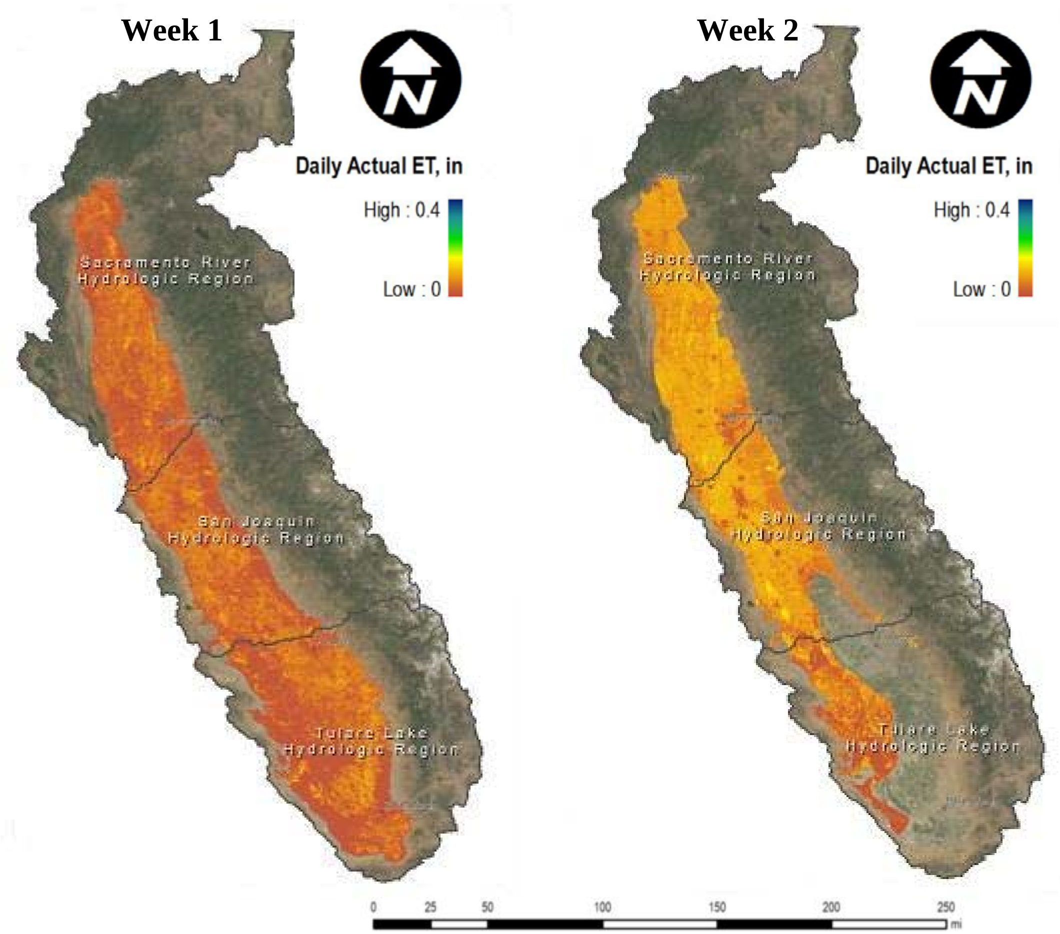
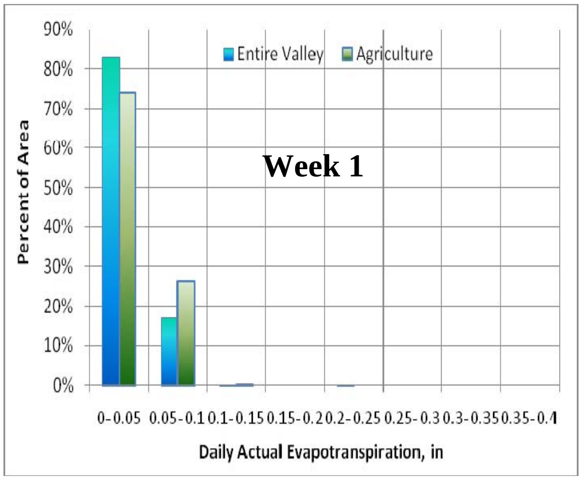


Figure 2. Spatially distributed ETa maps for the Central Valley. Week 1 is the period from 10/07 to 10/13 and week 2 is the period from 10/14 to 10/20.

Although changes in weather conditions that influence ET are taken into consideration by incorporating average weather conditions for the period represented by an image, events such as irrigation/and or precipitation on the day following the day of the image have not been explicitly accounted for. The effects of such irrigation/and or precipitation events are, however, represented in the image selected for the following period. This is apparent in the present case where a relatively greater ETa is seen in the Week 2 results, which represent the week starting on the 14^{th} of October, a day after the rainfall occurred.

Figure 3 summarizes the spatial ETa results from Weeks 1 and 2. It is apparent from Figure 3 that the areas with non-zero ETa have increased considerably in Week 2. The mean daily ETa rate summarized individually for SR, SJ and TL hydrologic regions was also greater in Week 2 (0.075, 0.070 and 0.038 in, respectively) than in Week 1 (0.028, 0.032 and 0.026 in, respectively). The overall increase in ETa apparent in Week 2 is primarily due to an increase in soil surface evaporation in Week 2 as compared to Week 1.



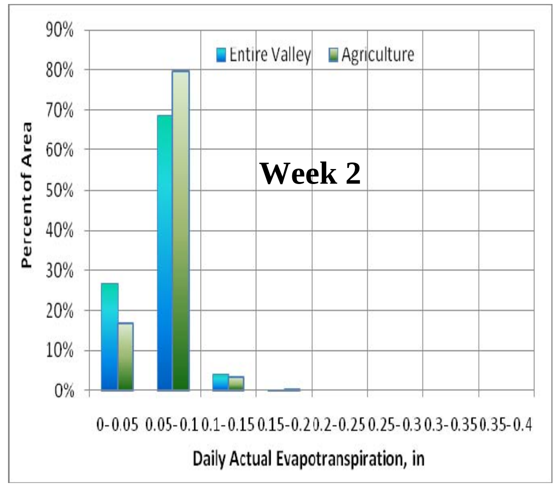


Figure 3. ETa Distribution in the Central Valley. Week 1 is the period from 10/07 to 10/13 and week 2 is the period from 10/14 to 10/20.

Lumped Crop Coefficients (Kcs). Maps of spatially distributed lumped crop coefficients and their histograms are presented in Figures 4 and 5, respectively. Week 1 results (Figure 5) show that more than 40% of the Valley as a whole has a Kcs of 0.2 or less. Crop coefficients for the agricultural area are similarly low with almost 80% of the area showing crop coefficient of 0.5 or less. The effects of bare fields and lack of soil moisture in the absence of irrigation or precipitation are apparent in the Week 1 Kcs values.

Crop coefficients in Week 2 follow a similar trend as ETa, showing an overall increase compared to Week 1 (Figures 4 and 5). Following the precipitation on the 13th of October, the increase in evaporation and evapotranspiration from Week 1 is apparent. Most of the areas in the Valley show non-zero Kcs values except for those areas that are potentially impervious surfaces e.g., rocks, foothills, or pavement, which are unable to hold moisture.

The increase in Kcs (Figure 5, Week 2) apparent in agricultural areas is due to increased soil surface evaporation or increased transpiration for existing vegetation.

The average daily Kcs values summarized individually for the SR, SJ and TL hydrologic regions for Week 1 were 0.28, 0.30 and 0.22, respectively. The average Kcs values in Week 2 for the SR, SJ and TL hydrologic regions were 0.91, 0.74 and 0.37, respectively and indicate an overall increase in Kcs in all the three hydrologic regions.

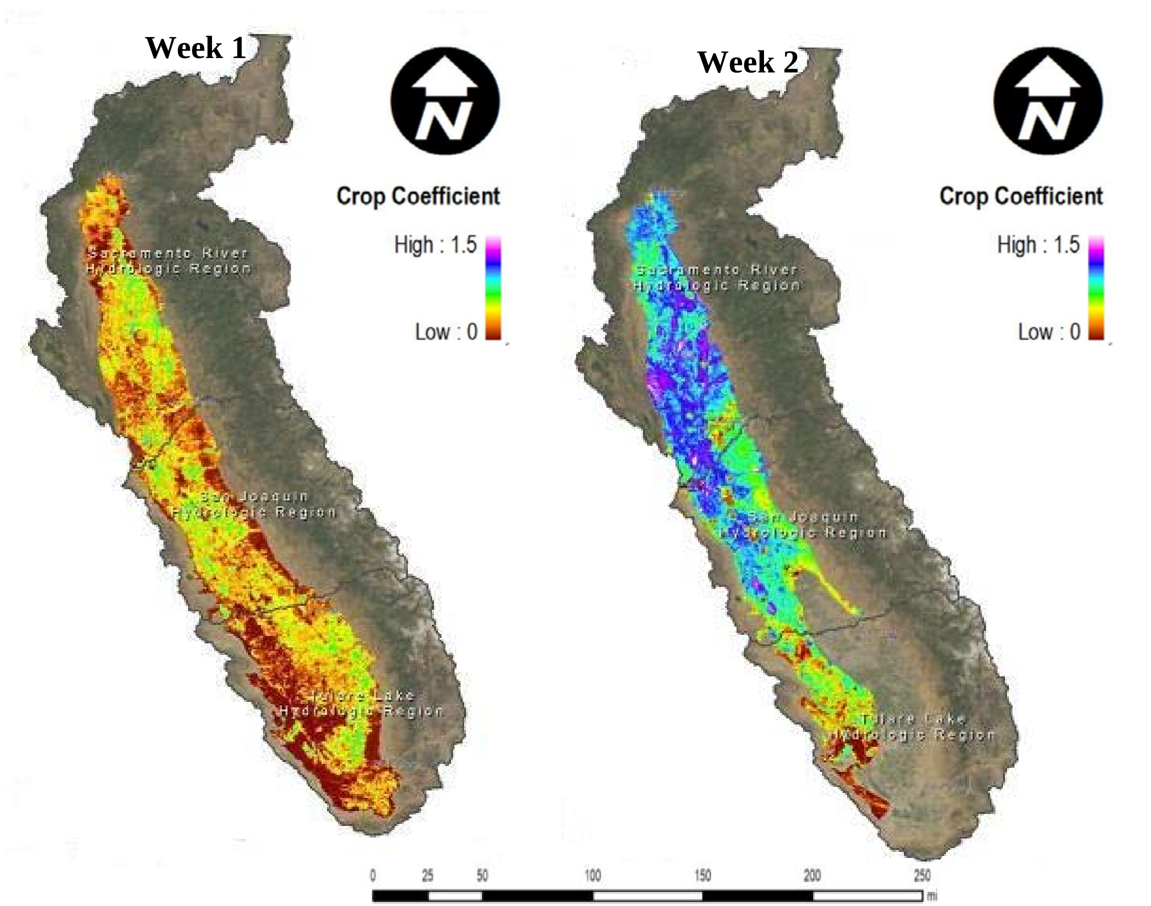


Figure 4. Spatially distributed weekly Kcs maps for the Central Valley. Week 1 is the period from 10/07 to 10/13 and week 2 is the period from 10/14 to 10/20.

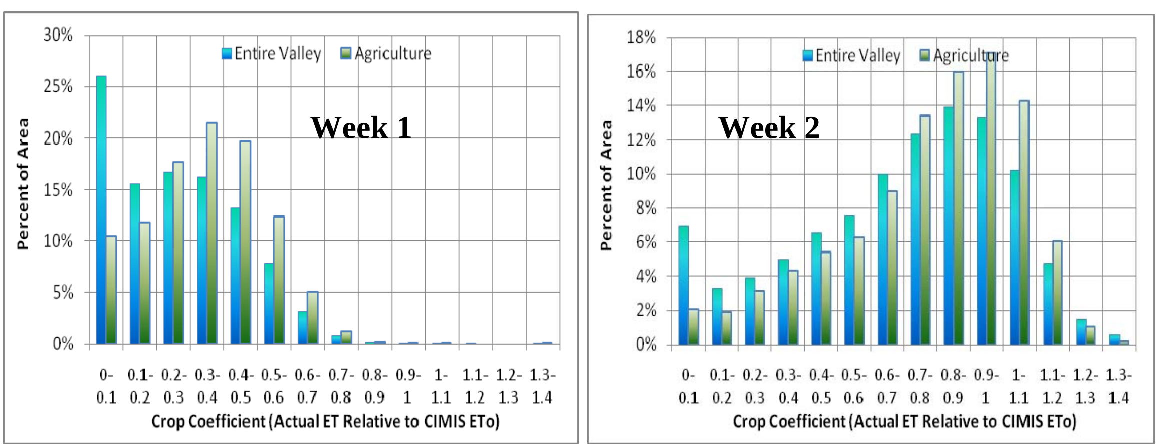


Figure 5. Kcs Distribution in the Central Valley. Week 1 is the period from 10/07 to 10/13 and week 2 is the period from 10/14 to 10/20.

Biomass Production. Maps of dry biomass production for the Central Valley and their frequency distributions for Weeks 1 and 2 are presented in Figures 6 and 7, respectively.

The biomass production in week 1 for SR, SJ and TL hydrologic regions was found to be 186, 211 and 168 lbs/acre respectively. An increase in Biomass was apparent in Week 2 with 199 and 239 lbs/acre of production for SR and SJ hydrologic regions respectively.

In Tulare Lake region, biomass production decreased from 168 lbs/acre in first week to 97 lbs/acre in the second week. This decrease in biomass production in TL region could be attributed to potential harvest that might have occurred before the satellite image acquisition that represents week 2 results or due to reduced PAR in Week 2.

An overall increase in biomass production for agricultural areas in the Valley is apparent in the 0 – 25 lbs/acre category for week 2 (Figure 7). This increase in biomass could be due increased transpiration rates (biomass being proportional to transpiration) of existing vegetation in the area. The precipitation event may also have initiated growth of new vegetation.

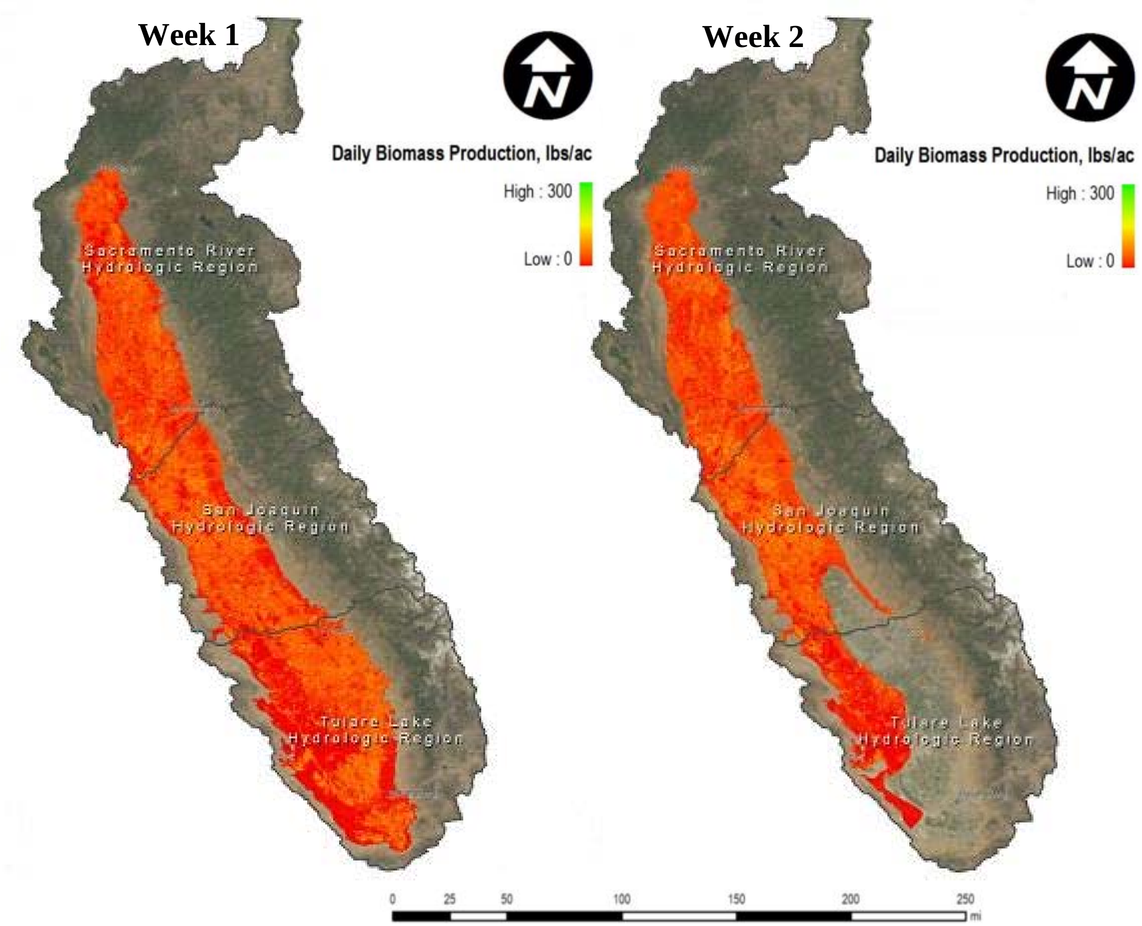


Figure 6. Spatially Distributed Weekly Biomass Production for the Central Valley. Week 1 is the period from 10/07 to 10/13 and week 2 is the period from 10/14 to 10/20.

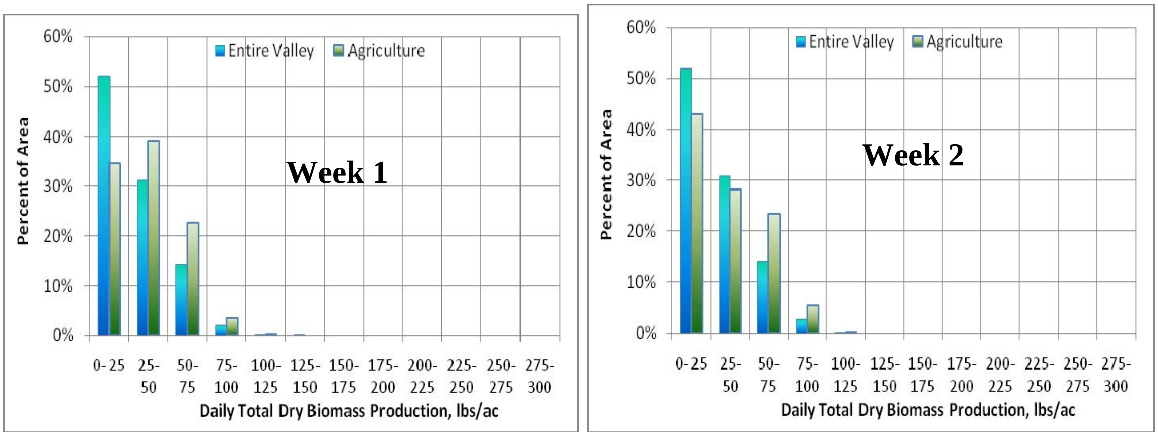


Figure 7. Biomass Distribution in the Central Valley. Week 1 is the period from 10/07 to 10/13 and week 2 is the period from 10/14 to 10/20.

DISCUSSION

The examples presented in Results section demonstrate that the SEBAL operational data products are able to capture variations in ETa, Kcs and Biomass, both spatially and temporally. These data offer efficient monitoring of crop consumptive use and production in near-real time which could assist irrigation districts, water agencies, growers, and water managers in general in decision making and natural resource management.

In addition to actual ET, the lumped crop coefficients (Kcs) developed using SEBAL are useful for irrigation management and planning. The lumped Kcs represent actual growing conditions for a given crop and can be utilized to determine accurate crop water requirements.

Weekly biomass production estimates can be used to improve crop management and to understand drought impacts. Biomass production can be utilized to monitor overall crop growth, incorporating the effects of environmental and management related stresses including disease, pests, moisture stress, fallowing, etc. Biomass production can be utilized to predict yield for a given crop by using crop specific harvest indices (Bastiaanssen and Ali, 2003). Predicting yield could help in assessing the value of a crop prior to coming into the market. Additionally, biomass production and ET can be combined to estimate water productivity of a given crop. Water productivity is defined as the crop yield per unit of water used and is a useful index to gauge water use efficiency.

CONCLUSIONS

Satellite based near-real time ET, Kcs and Biomass are being generated using SEBAL on a weekly basis. SEBAL is the most widely applied energy balance model for estimating ET, and over the years it has been validated in various parts of the world, including California.

Weekly data are available for California's Central Valley with a spatial resolution of 250 m. Satellite images from MODIS along with weather data from CIMIS have been utilized to generate these data products. Operational products for most recent weeks can be accessed on SNA's website (www.sebal.us). The SNA website is updated every week with the operational products for the prior week.

Using MODIS images, actual ET, crop coefficients, and biomass production can be estimated in a near-real time. Water supplies in the Central Valley are limited, and efficient utilization of available water is critical. Detailed water consumption patterns provided by spatially distributed weekly ET maps along with Kcs and Biomass can assist in improving understanding of water use in both agricultural and natural systems.

REFERENCES

Bastiaanssen, W. G.M., Noordman, E. J. M., Pelgrum, H., Davids G., Thoreson , B.P. and Allen, R. G., 2005. SEBAL model with remotely sensed data to improve water-resources management under actual field conditions. ASCE J. Irrig. Drain Eng. 131(1): 85-93.

Bastiaanssen, W. G.M. and Ali, S, 2003. A new crop yield forecasting model based on satellite measurements applied across the Indus Basin, Pakistan. Agri. Eco. Environ. 94 (2003) 321-340.

Cassel S., Florence., 2006. Final Report: Remote Sensing of Evapotranspiration for Verification of Regulated Deficit Irrigation. Project #04FG203069. United States Bureau of Reclamation.

Field, C.B., Randerson, J.T., Malmstrom, C.M., 1995. Global net primary production: combining ecology and remote sensing. Rem. Sens. Environ. 51, 74-88.

Monteith, J.L., 1972. Solar radiation and productivity in tropical ecosystem. J. Appl. Ecol. 9, 747-766

Morse, A. "Comparison of Ground Water Monitoring Costs as a Reason to Maintain the Thermal Band on the Landsat Data Continuity Mission: A Quick Look," Internal Report to the Idaho Department of Water Resources, Boise, Idaho. Feb. 18, 2003.

Soppe, R.W., Bastiaanssen, W., Keller, A., Clark, B., Thoreson, B., Eckhardt, J., and Davids, G., 2006. Use of High Resolution Thermal Landsat Data to Estimate Evapotranspiration within the Imperial Irrigation District of Southern California. Oral Presentation, American Geophysical Union 2006 Fall Meeting, San Francisco, California.

DEVELOPING REVENUE GENERATING INFRASTRUCTURE: FRESNO IRRIGATION DISTRICT'S WALDRON BANKING FACILITIES

Randy Hopkins, PE[1]
Bill Stretch, PE[2]

ABSTRACT

Fresno Irrigation District (FID) serves irrigation water to approximately 245,000 acres including the Cities of Fresno and Clovis, in California's Central San Joaquin Valley. As Clovis has developed they have looked for ways to diversify their water supply portfolio. Until recently, this mainly consisted of groundwater wells with some surface water supplies coming from FID. Clovis, in an effort to increase their dry year supplies, partnered with FID to develop the Waldron Banking Facilities.

The Waldron Banking Facilities consist of three groundwater banking facilities located in the western portion of the FID. Through the agreement developed between Clovis and FID, Clovis provided half of the capital to develop the project in return for half of the project yield. Clovis also has the first right of refusal, on an annual basis, for any yield developed from the project. In exchange for the banked supplies, FID then provides an equivalent amount of surface water to Clovis (in the eastern portion of FID). To develop a new water supply for Clovis and FID, during wet years and other times when surplus surface water supplies are available these supplies are routed to the groundwater recharge basins. In dry years, these banked supplies are then recovered from the aquifer, and delivered to FID growers, with 10% of all banked water being left behind to benefit the local aquifer.

This paper will focus on the financial aspects of the project and provide an example of how a district can develop new, revenue generating infrastructure, in the current economic environment.

BACKGROUND

The Waldron Banking Facilities Project (Project) is a groundwater banking project that provides water to urban and agricultural water users, and facilitates the environmental benefits of improving a river fishery. The Project is divided into three separate facilities totaling 250 acres (Waldron – 160 ac., Empire – 32 ac., Lambrecht – 58 ac.). Figure 1 is a map of the FID showing the locations of the three sites, and the channels used to convey surface water to them.

The new supplies are developed by capturing flood waters and surplus supplies in above normal years and recovering them during below normal years, rather than letting those

[1] Project Manager, Provost and Pritchard Consulting Group, 2505 Alluvial Ave. Clovis, CA 93619
rhopkins@ppeng.com
[2] Chief Engineer, Fresno Irrigation District, 2907 S. Maple Ave. Fresno, CA 93725
bstretch@fresnoirrigation.com

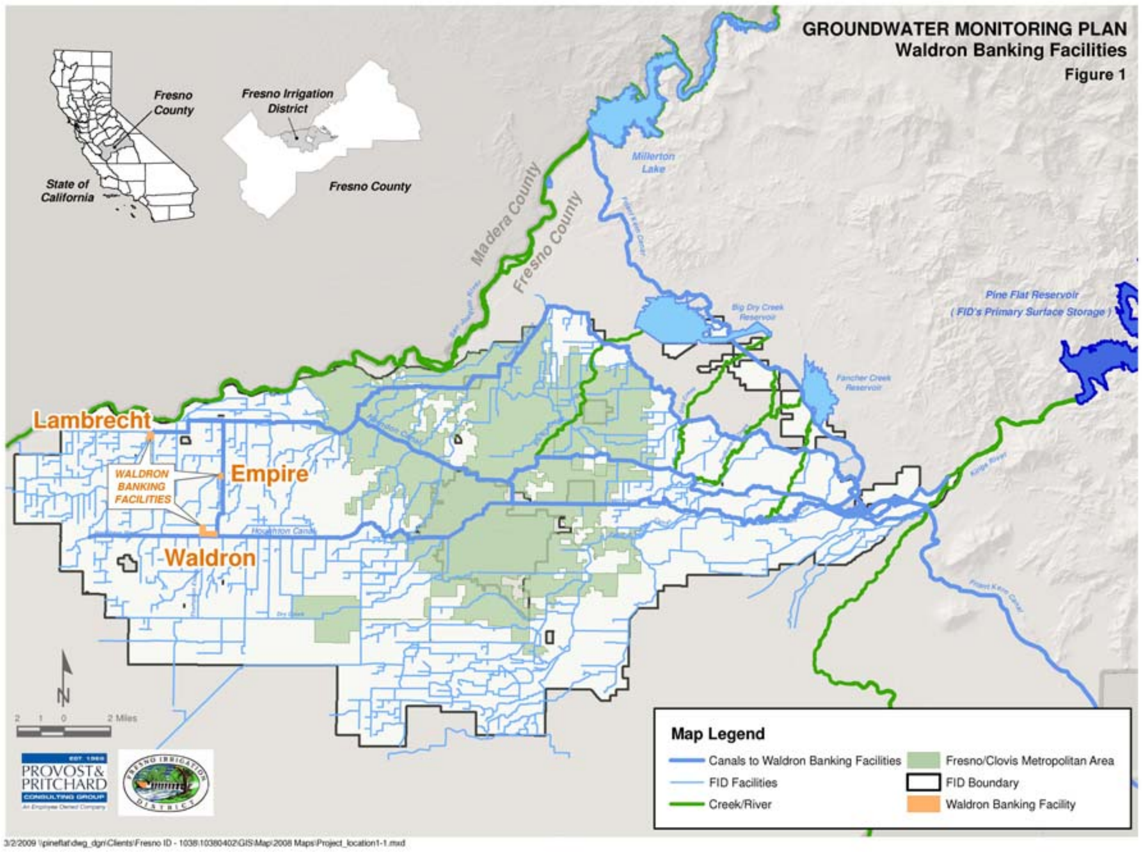


Figure 1. Map of the Waldron Banking Facilities

supplies go unused during the above normal years. The Project utilizes a combination of urban and Kings River flood water, fisheries management water, allocations from the San Joaquin River during above normal years, and flood water from the San Joaquin River.

A review of the records from the 50 years prior to the study showed that on average approximately 11,500 AF could be routed to the Project for recharge. Leaving 10% of the recharged water behind to account for losses and mitigate potential impacts to adjacent landowners, the Project would net approximately 10, 350 AF on an average annual basis.

DESIGN CONSIDERATIONS

The Project's design took into account a number of factors such as how quickly water could be placed into the basins, and recovered from the aquifer. In addition, the District wanted to make the best use of its capital investment, so each of the sites was designed to include flow regulation capabilities. Upgrades to the control gates and SCADA improvements were included.

Location

The Projects were sited such that they would:

1. Have geology favorable to groundwater banking.
2. Be far enough upstream in the FID's distribution system that all of the recovered water could be used to satisfy downstream irrigation demands.
3. Be strategically located to regulate flows on main canals.

Recharge

The sites' primary purpose is water banking with flow regulation and operational storage a secondary benefit. Geologic explorations of each site were conducted to verify if the shallow soil profiles would be conducive to recharge. Explorations of the deeper aquifer were also performed to determine the zones from which to draw the stored water. The geologic investigations and infiltration tests showed the sites' could sustain recharge rates between 0.35 and 0.5 ft per day. The recharge goal for between the three sites totals 13,000 AF (in anticipation of above average conditions) in the ground in approximately 8 months, or an average of 1,600 AF per month (0.21 feet per day). All of the sites had estimated sustainable recharge rates which were higher than the 0.21 feet per day needed which gave the District the ability to shorten the recharge season when needed.

Recharge could come in highly irregular flows and short bursts. Also, when recharge basins are being filled for the first time, they will percolate at much higher rates. Recognizing the potential for the need to take high flows in short bursts, many design features were incorporated. The turnouts to each site were designed for relatively high flows and sediment handling. The sites divided into smaller cells to help manage spreading and evaporation.

Table 1 below lists the sustainable recharge rate, acreage, and delivery inflow for each site. As the table shows, the design inflows are a minimum of about four times higher than the sustainable recharge flow. At the Empire and Lambrecht sites, the design inflows were based on the maximum flow that could be routed to the sites.

Table 1. Summary of Recharge and Inflow Rates.

Site	Sustainable Recharge Rate (ft/day)	Acreage	Sustainable Recharge Inflow (cfs)	Design Inflow (cfs)
Waldron	0.35	160	32	130
Empire	0.35	32	6	60
Lambrecht	0.50	58	15	90

Each site was divided into a number of cells. This gives the FID the operational flexibility to fill basins in a sequence which would maximize surface storage using the least amount of acreage. This reduces evaporation losses and helps to minimize maintenance activities such as discing and spraying to control weeds, in years when large volumes of recharge water are not available. Without dividing the sites into smaller cells, water would be spread over much larger areas.

Given the source of the recharge water (floodwater, urban stormwater) it was anticipated that high sediment loads and trash would be delivered with the water. To mitigate the sediment one cell at each site was dedicated as a sediment cell. Dedication of the sedimentation cell also keeps sediment in one portion of the facility reducing maintenance, and reducing the potential for fine sediment sealing off the recharge cells. The sediment cell was designed with partial levees to create a labyrinth in which to slow water flow through the basin. The discharge out of the sedimentation cell to the other cells utilized a weir. This was done so that water from the top one foot of the sediment cell (the clearest water) would be delivered to the other recharge cells.

Recovery

Seven wells were built for the Project. They can recover up to 12,000 AF of stored water in four months. All three sites are in cropped areas and many of the growers have their own wells. The project wells can pump between 2,000 and 4,000 gpm with average pumping depths of about 180 feet. All of the wells are equipped with flowmeters that totalize the amount pumped. The recovery wells were drilled at lower depths than the surrounding wells in an effort to minimize interference. Typically, the nearby irrigation wells are completed to a depth around 300 to 400 feet. The recovery wells were completed to a minimum depth of 500 feet. Table 2 below lists the recovery capability for each site.

Table 2. Recovery Ability Summarized by Site

Site	Recovery Flow (cfs)	Number of Wells
Waldron	22	3
Empire	6	1
Lambrecht	22	3

A monitoring network was also developed around the sites. The network involves on-site and off-site wells. A total of 10 monitoring wells were built at the sites to collect more detailed information about how the Project is affecting local groundwater conditions. FID collects water levels at least monthly in the monitoring network. The data is used to determine groundwater elevations, and determine groundwater flow direction. This includes determining the extents of pumping depression or recharge mounds, if any, which could result from the Project operations.

PROJECT FUNDING AND COSTS

Project Funding

While 10,350 AF of supply represents about 2 to 3% of FID’s dry year supply from the Kings River, it represents a significant dry year supply to the City of Clovis (Clovis). Clovis typically uses 25 TAF in a normal year, 70% is derived from surface water and 30% from groundwater wells.

In planning for new growth, Clovis recognized the need to develop a new water supply and further increase its dry year supply. This need for new water supplies led Clovis to partner with FID to develop the Project. As partners in the Project, Clovis agreed to fund half of the capital cost of the Project in exchange for half of the Project’s yield. Clovis is given first right of refusal for water each year. Clovis is guaranteed 90% of the available banked water in any given year, up to 9,000 AF. If Clovis does not take water in a year, FID has the ability to use the water to serve their growers.

In 2000, California voters approved Proposition 13, the *Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection Act* (Prop 13). FID submitted a grant application under Prop. 13's Groundwater Storage Program to fund their half of the Project's costs. FID was awarded the grant and signed the contract to commence with the Project in 2004. The contract required that the Project be finished by the end of 2008.

Project Costs

Capital Costs. Initial capital costs to develop the Project were significant. Approximately $10.7 million was spent to develop the Project. This includes the costs to purchase the land, as well as to construct the basins, structures, recovery wells, and monitoring wells. With the average annual net yield of 10,350 AF, the capital cost to develop this new supply calculates to approximately $1,030 per AF. The following table breaks down the capital costs into the major cost components.

Table 3. Proportions of the Major Capital Cost Components

Item	Portion of Cost
Land Acquisition	15%
Basins and Structures	39%
Recovery Wells	33%
Monitoring Wells	3%
Other	10%

Operations and Maintenance Costs. Operations and maintenance (O&M) costs for the project consist of the costs of maintaining the basins, wells and other facilities including the additional labor, and the power to operate the facilities. In addition, there are on-going costs associated with water quality testing for both the recovery wells and the surface water conveyed to the recharge basins, monitoring of groundwater levels in the vicinity of the recharge sites, and the costs associated with purchasing flood water from the Central Valley Project when available. Combined, the unit cost associated with operating and maintaining the project is approximately $140 per AF of net yield. These costs are constantly monitored by FID, and generally updated annually. The following table itemizes the major cost components of the O&M costs.

Table 4. Proportions of the Major O&M Cost Components

Item	Portion of Cost
Wells	33%
Basins	26%
Water Quality Monitoring	9%
Water Supply	25%
Other	7%

REVENUE POTENTIAL

FID's agreement with Clovis allows Clovis to purchase the water for the O&M cost. This generates revenue for FID, but not enough to offset broader costs in FID. However, in the event Clovis does not purchase any supply from the Project, FID may provide the water to their customers, or to other water users through transfers. If the water is transferred to other water users, FID has the potential to generate significant additional revenues which can be used to offset their overall costs in the FID, make improvements within the FID, or build reserve accounts. FID is planning to pursue all of these options.

In California, wholesale water prices vary widely from year to year, depending on the type of water year (wet, normal, or dry). In dry years, transfers[3] can generate as much as $500 per AF of water supplied, or more. In wet years, these same transfers may only be able to generate $100 per AF. Any number of assumptions could be made about what could happen in the future, and how things could work. The following table summarizes how the range in prices can affect the net revenue FID could receive from a transfer.

Table 5. Assumed Wholesale Price and Net Revenue

Wholesale Price ($/AF)	$150	$200	$250	$300
O&M Cost ($/AF)	$140	$140	$140	$140
Net Revenue ($/AF)	$10	$60	$110	$160
Net Revenue at 5,000 AF	$50,000	$300,000	$550,000	$800,000
Net Revenue at 10,000 AF	$100,000	$600,000	$1,100,000	$1,600,000

The transfers presented above show that when the wholesale price for water reaches between $200 and $250 per AF, it begins to make sense financially for FID to consider transferring water. If even 5,000 AF (half of the Project's average annual yield) is transferred then FID could offset about 3% of its budget. When prices reach $300 per AF and if FID is able to transfer 10,000 AF then it could offset 16% of their annual budget.

SUMMARY

Water banking and management programs have been proven successful for many districts in California as a means to generate revenues, create additional supplies, and help manage groundwater levels. FID operates their 680+ miles of canals and pipelines on an annual budget of approximately $10 million. As with many irrigation districts, they strive to keep the taxes assessed on their landowners to a minimum. As stated previously, 10,000 AF represents about 2-3% of FID's average annual supply. With this minimal supply (all of which is in addition to their normal supply) FID is able to offset a significant amount of its annual budget. This allows FID to build reserves, make improvements to the district, and maintain all of their facilities, all while keeping tax assessments relatively low.

[3] Transfers in this paper are defined as a single occurrence in a single year, and not an on-going obligation to provide or purchase water.

COST SHARING PARTNERSHIPS FOR MUNICIPAL INTERBASIN TRANSFER AND AGRICULTURAL WATER CONSERVATION

Stacy Pandey[1]
Ana Ramirez[2]
John McLeod[3]

ABSTRACT

The House Bill 1437 (HB 1437) Agriculture Water Conservation Program is an innovative way to meet rising municipal demands in a county adjacent to the Lower Colorado River Authority (LCRA)'s service area in central Texas, conserve river water used for irrigation, and maintain agriculture productivity. A cooperative program between municipal and agricultural water users, and the Natural Resource Conservation Service's Environmental Quality Incentive Program (EQIP) provides grants to irrigation divisions and agriculture producers in Matagorda, Wharton, and Colorado counties to implement agricultural water conservation projects.

Responding to requests for an interbasin transfer mechanism from utilities in Williamson County pressured with high population growth rates and limited water supplies, in 1999, the Texas Legislature passed HB 1437. HB 1437 authorized LCRA to transfer up to 25,000 acre-feet of water per year to Williamson County under certain conditions including "no net loss" of water to the lower Colorado River basin, and a conservation surcharge on the transferred water collected from customers in Williamson County dedicated to a specific fund to help pay for agricultural conservation projects.

The grant program began in 2006 and from 2006-2008 has funded a 30% cost share to precision level 12,161 acres of farm land already participating in the 50% cost share federal EQIP program. A 3-year average of 3,597 acre-feet of water has been conserved as a result of these precision land leveling grants. LCRA has partnered with the Lyndon Baines Johnson School of Public Affairs at the University of Texas to develop a sound statistical methodology for determining water savings from precision leveled fields. Preliminary results of this analysis indicate that there is a statistically significant difference in water use between leveled and non-leveled fields. More in-depth statistical analyses are to be completed by Spring 2010. The 5-yr program plan goal is to conserve 10,000 acre feet per year by 2014, using a combination of conservation projects including precision land leveling grants, on-farm volumetric measurement and billing, and automating existing canal check structures.

---

[1] Senior Water Conservation Coordinator, Lower Colorado River Authority, 3700 Lake Austin Blvd, Austin, TX 78703, stacy.pandey@lcra.org

[2] PhD candidate, LBJ School of Public Affairs, University of Texas at Austin, akramirezh@yahoo.com

[3] Senior Project Manager, Lower Colorado River Authority, 3700 Lake Austin Blvd, Austin, TX 78703, john.mcleod@lcra.org

INTRODUCTION

HB 1437 Enabling Legislation

Due to high population growth rates and limited water supplies, water utilities within Williamson County have had to look outside of their river basin to meet projected demands for water. Williamson County lies within the Brazos River Basin, which is adjacent to the Lower Colorado River Basin in Texas (Figure 1). House Bill (HB) 1437, passed by the Texas Legislature in 1999, authorizes the Lower Colorado River Authority (LCRA) to provide up to 25,000 acre-feet of surface water per year for use in specific areas of Williamson County. The LCRA is a conservation and reclamation district created by the Texas Legislature in 1934. LCRA supplies electricity for Central Texas, manages water supplies and floods in the lower Colorado River basin through the operation of six dams, manages three irrigation divisions, develops water and wastewater utilities, provides public parks, and supports community and economic development in 58 Texas counties.

According to HB 1437, this water would be transferred under four major conditions:

1. Water is transferred in a manner that assures “no net loss” of surface water to the Colorado River Basin.

2. A conservation charge for transferred water is added to the base water rate, with proceeds from the conservation charge to be deposited into the Agricultural Water Conservation Fund (Ag Fund). The legislation set a minimum 10 percent conservation charge and authorized the LCRA Board to adjust the conservation charge as necessary to mitigate any adverse effects of the transfer.

3. The Board may use money from the fund only for the development of water resources or other water use strategies to replace or offset the amount of surface water to be transferred to Williamson County.

4. LCRA consults with an advisory committee, comprised of representatives from Colorado, Wharton and Matagorda counties, prior to using funds from the Agricultural Water Conservation Fund.

Interbasin Permit and Water Contract

In October 2000, LCRA and Brazos River Authority (BRA) signed a 50-year water sales agreement for the 25,000 acre-feet of water. In addition to the standard contract provisions, the agreement included a 25 percent conservation charge for transferred and reserved water and a clause that allows BRA to terminate the agreement not earlier than February 15, 2012.

In August 2001, the Texas Natural Resource Conservation Commission issued the interbasin transfer permit to BRA to transfer up to 25,000 acre-feet of water per year to

Williamson County under the conditions authorized in HB 1437. As of October 2009, no water transfers have occurred.

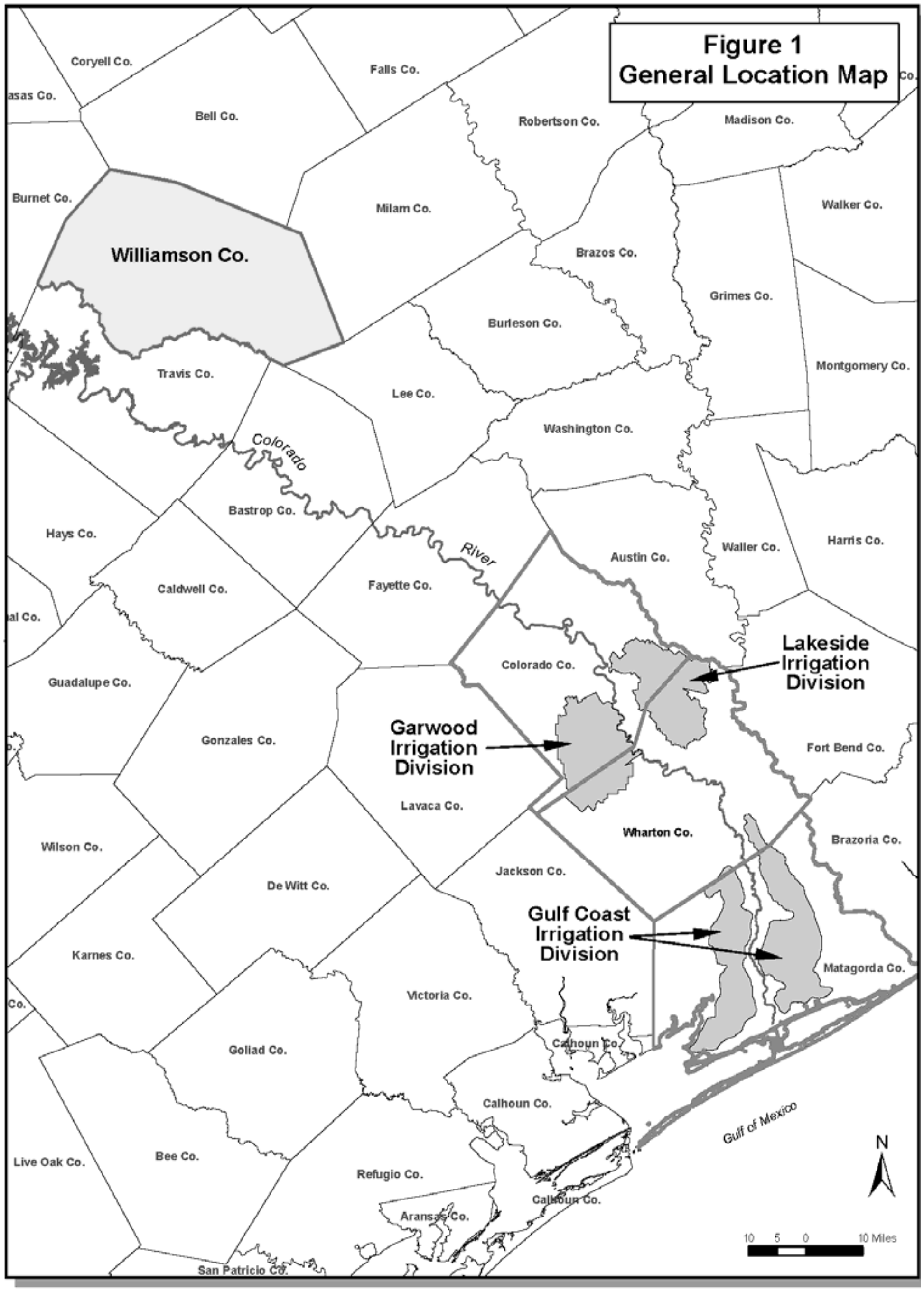


Figure 1. General Location Map

HB 1437 Implementation Study

In 2004, the LCRA Board authorized an engineering study and public meetings to develop a plan for implementing the HB 1437 program. Major goals of the study were to define the term "no net loss," evaluate potential conservation projects and develop an implementation plan to allow the water transfer to occur under the provisions of the HB 1437 legislation. The plan, developed after review and comment by the Brazos River Authority, municipal customers, local farmers and members of the public, developed a definition for "no net loss," developed a seven-year plan to meet projected water demands through on farm and in-district conservation projects, established a 25 percent conservation surcharge on the water transferred to Williamson County customers, and presented additional recommendations for program implementation.

The development of this plan followed an extensive public input process. A total of 18 water replacement strategies were evaluated in two rounds of public meetings conducted in three locations throughout the basin. Stakeholders who participated in the process included people who live close to the Highland Lakes, people who farm and use irrigation water, LCRA and BRA water customers, environmental group representatives, and the City of Austin. The primary screening criteria used to create a refined set of viable strategies were: cost to the customer, phased implementation, accelerated implementation, sustainable yield, permits, meets definition of "no net loss" and mitigates adverse impacts. Secondary screening criteria were applied to identify and prioritize impacts and benefits of strategies, balance subjective project impacts against implementation costs and score total project impacts and costs equitably. The five final strategies selected as a result of this process included: precision leveling, automated check structures and SCADA control system, balancing reservoirs, conjunctive use of groundwater, and reduced irrigation for 2nd crop. More details on this process are contained in the study document, which is available at www.hb1437.com.

This study also determined a definition for "no net loss" which resulted in the adoption of LCRA Board Policy 501, "Water Resources," that incorporated the demands of HB 1437 Agricultural Water Conservation Program. This revised policy was adopted by the LCRA Board in March 2005.

<u>No Net Loss</u> No Net Loss is defined in the LCRA Board Policy 501 as a hydrologic condition where the average annual volume of Transferred Water is equivalent to, or less than, the combined average annual volume of Conserved Water, Developed Water, and Returned Water resulting in a reduced reliance on surface water for agricultural irrigation. This is expressed below in equation form.

Transferred Water < Conserved Water + Developed Water + Returned Water

Transferred Water is the average annual volume of surface water exported from the lower Colorado River basin to Williamson County under the Texas Water Code (which reflects the original legislation). Conserved Water is the average annual volume of water developed under HB 1437 from conservation projects and demand reduction projects within the water service areas of LCRA's irrigation divisions. Developed Water is the average annual volume of additional water made available for use within the water service areas of LCRA's irrigation divisions and may include any groundwater or surface water resources that are not presently under the control of LCRA. Returned Water is the average annual volume of water that is imported to the lower Colorado River basin with the specific intent to meet the conditions of the Texas Water Code. Average annual volume is defined as the arithmetical average volume of water over a contiguous 3-year period. This averaging provision was included in the policy and allows for flexibility in adding groundwater and reuse water from outside the Lower Colorado River watershed to balance any unexpected diversions within the averaging period. Conserved Water that is not transferred is lost but as more conservation practices are implemented, the average yearly volume of transferrable water increases.

NRCS Memorandum of Understanding

In March 2007, the LCRA and the Natural Resources Conservation Service (NRCS) entered into an agreement to share technical information related to the NRCS's Environmental Quality Incentives Program (EQIP). This federal grant reimburses producers 50 percent of the cost of specific on-farm conservation projects such as precision land leveling. In 2006, LCRA Board adopted the application guidelines, eligibility rules and contract provisions for awarding cost sharing conservation grants from the Ag Fund. These guidelines integrated the NRCS technical specifications and payment certification processes into the requirements for the HB 1437 grant program. This agreement is an important mechanism for reducing administrative costs as well as the actual cost-share burden for LCRA by adopting NRCS' existing certification program for EQIP funded water conservation projects.

PROGRAM OVERVIEW

The HB 1437 Agricultural Water Conservation Program is a major part of the LCRA's water conservation program for agricultural uses. The program joins individual producers, local soil and water conservation districts, and the NRCS in a collaborative effort to conserve water. The following are the goals of the HB 1437 program:

1. Reduce agricultural use of surface water;

2. Plan and implement conservation projects to fulfill obligations of the LCRA/BRA contract for HB 1437 water;

3. Provide grants from the Agricultural Water Conservation Fund to implement water conservation projects; and

4. Provide program performance information to the LCRA Board, BRA water customers, and the public in accordance with LCRA Board Policy 501.

Demand Projections for HB 1437 Water

The water demand projections were developed by the Brazos River Authority and its customers, and are reviewed and updated annually. Figure 2 compares the HB 1437 water demands used to develop the current HB 1437 implementation plan with the updated demand projections recently provided by BRA and their customers. The updated projections indicate an initial delay in demand, relative to the previous projections, followed by a more uniform growth in demand.

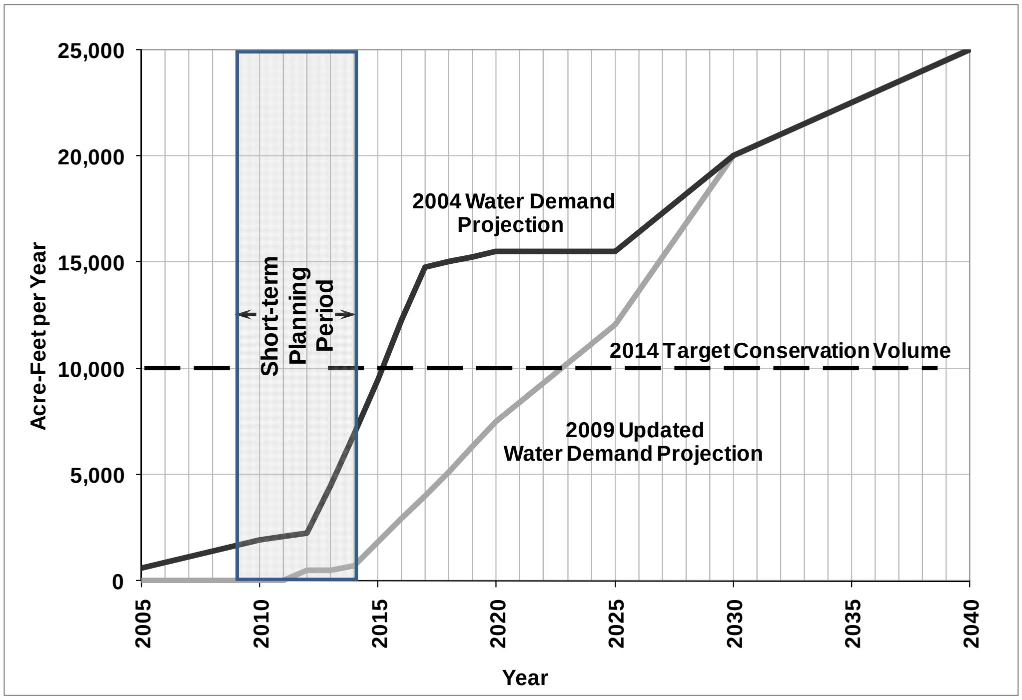


Figure 2. Water Demand Projections for HB 1437 Water

Updated Program Plan

The initial HB 1437 program plan was developed during the 2005 implementation study and includes a combination of on-farm and in-division conservation improvements to meet the projected water demands of BRA water customers in Williamson County. This plan developed 3,500 acre-feet of conservation, primarily through providing supplemental grant funds to precision grade 6,000 acres by the year 2012.

The program plan was recently updated to include a series of projects and studies to be completed during the period 2009 to 2014. The goal of this short-term plan is to develop 10,000 acre-feet of HB 1437 water per year for transfer to Williamson County by 2014. This target provides for development of conservation improvements 4 to 6 years ahead of their need while accounting for other uncertainties, such as reliability of conservation during drought. It also allows for leverage of the HB 1437 funds through acquisition of other grants that may not be available in the future. A summary of the HB 1437 program plan is presented in Table 1.

Table 1. 2010-2014 Conservation Projects and Program Costs

On-Farm Projects	In-Division Projects	Studies and Management
Precision level 12,500 acres of farmland (2,500 acres per year)	Implement volumetric measurement in the Garwood Irrigation division Retrofit to automate eleven canal check structures in LCRA's irrigation divisions	Conservation measurement and monitoring
Construction Cost - $1.203 million	Construction Cost - $1.519 million	Oversight and customer communication
		Program administration
Total cost: $8.008 million **Funding sources:** Ag Fund - $3.097 million, EQIP & TWDB Grant – $2.833 million, Farmer - $2.077 million **HB 1437 Water Available for Transfer**: 10,000 acre-feet per year		

<u>Program Funding</u>

The program is funded through the income stream generated from the conservation surcharge applied to the water sales contract. The conservation surcharge is applied to both reserved water and transferred water. The conservation surcharge rate must be sufficient to maintain a positive balance in the Ag Fund. Income to the Ag Fund is based on the following rates:

• Conservation Surcharge 25%	• Max Available Water: 25,000 ac-ft/yr
• Normal Raw Water Cost: $138/ac-ft	• Reserved Water Cost: $69/ac-ft

<u>Schedule</u>

The current implementation plan projects that at least 10,000 acre-feet of HB 1437 water would be conserved and be available for transfer to Williamson County by the year 2014.

Precision leveling will continue to be funded at a level of 2,500 acres per year, the Garwood volumetric measurement project will begin in 2010 and will be completed in 2012. In-division canal check structure retrofits will begin in 2012 and continue until 2014.

PROGRAM RESULTS

Program and Policy

In December 2008, the HB 1437 Application Guidelines and the HB 1437 Cost Sharing Agreement were amended so that conservation funds for precision leveling are distributed pro rata among qualified applicants rather than limiting the award of grant funds based on a lottery selection system.

Under the previous lottery method, if the dollar amount of highest priority qualified applications exceeded the grant budget for that year, payments from the Ag Fund would be awarded based on a lottery ranking of qualified applications. Under this lottery method with a fixed 30 percentage cost share, a highly ranked, and large acreage application could effectively use up all of the available funds, eliminating other worthy projects.

While LCRA staff has received favorable comments regarding the prioritization of conservation projects (these prioritizations take into account whether the applicant has completed the steps necessary to obtain an EQIP agreement as well as the status of the leveling project) the lottery ranking component has been the subject of farmers' concerns. Therefore, beginning in 2009, an annual grant budget was set for expenditures from the Ag Fund and those expenditures, subject to NRCS guidelines for leveling costs, was spread across all qualifying applicants with the same priority ranking within a budget year on a pro rata basis. This Board action also limited expenditures to any single applicant to a maximum of 30 percent of the cost of the applicant's precision leveling project, and the total grant amount (EQIP plus HB 1437 Ag Fund) to an applicant to an amount that could not exceed 100 percent of the applicant's project costs. Even though applications far exceeded budgeted funds in 2009, resulting in a payout of only 12%, LCRA customers accepted this method as an equitable way to distribute grant funds.

On-Farm Conservation Projects

The total on-farm conservation projects completed from the program inception in 2006 to 2008 is presented in Table 2. The grant program shared the cost of precision leveling of 159 fields totaling 12,161 acres. The largest acreage was in the Lakeside Irrigation Division (50 percent), followed by Garwood (45 percent) and Gulf Coast (5 percent). All program projects were funded by a combination of funds: 50 percent cost share from the Natural Resource Conservation Service (NRCS)'s Environmental Quality Incentive Program (EQIP); 30 percent funding from the Ag Fund; and the remaining 20 percent from producers. The average area of a leveled field was 77 acres.

Since inception, the HB 1437 Ag Fund has contributed $967,299 out of a total cost of $3,247,302. The average area of a leveled field was approximately 77 acres. The average cost to precision level was approximately $267 per acre.

All of the applications submitted in 2006-2008 that met the first priority criteria were funded. The priority criteria can be found in the HB 1437 Application Guidelines on http://www.hb1437.com.

Table 2. 2006-2008 Acres Leveled and Grants Awarded

Division	Fields Leveled	Acres Leveled	Total Cost	HB 1437 Share
Garwood	67	5,402	$1,326,418	$395,504
Lakeside	84	6,186	$1,784,960	$531,018
Gulf Coast	8	572	$135,924	$40,777
Total	**159**	**12,161**	**$3,247,302**	**$967,299**

Figure 3 shows the locations of the leveled fields in the Garwood, Lakeside divisions. There are very and Gulf Coast irrigation divisions.

In-Division Conservation Projects

There were no HB 1437 funded in-division conservation projects during the period 2006-2008. Preliminary design work was completed for the Garwood measurement project in early 2009 and construction work was started in the fall of 2009. This work is funded by a combination of HB1437 funds and a 2009 grant from the Texas Water Development Board.

Conservation Monitoring and Measurement

Accurate water conservation estimates are critical to water availability estimates necessary to comply with the "no net loss" requirement for water transfers. A major goal of the HB 1437 program is to continue to refine a technically sound water conservation monitoring plan that could be integrated and implemented within the normal business practices of the LCRA irrigation divisions. Studies by others have examined the role of precision leveled fields in agricultural water conservation (Goel et al. 1981, Anderson et al. 1999, Bjornlund et al. 2009, Smith et al. 2007) and have identified several factors that affect the utilization of conservation technologies and water savings, such as a farmer's age, education, dependence on off-farm work, size of farm operation, a field's ownership, quality of land leveling work and water costs.

The methodology to estimate the water conservation factors for the HB 1437 program is based upon a statistical comparison of water use in fields leveled to EQIP standards versus water use in other non-leveled fields. This concept will be verified by analyzing water use data from the Lakeside Irrigation Division for the 4-year period 2006 through 2009. Preliminary results from an analysis of 2006-2007 data show that the difference in water use between the HB 1437 fields and other fields is consistent with the 0.75 acre-feet of water saved per acre leveled conservation factor currently used to estimate water conserved under the HB 1437 program. The conservation monitoring plan calls for the development of separate conservation factors for each irrigation division.

A major challenge in implementing a HB 1437 conservation monitoring program is that only two of the three LCRA irrigation divisions currently volumetrically measure water delivered to fields. Historically, the Garwood division did not measure water at individual fields, yet nearly half of the acreage in the HB 1437 grant program is in this division.

To address this condition, staff has implemented a limited water measurement program in several sections of the Garwood Irrigation Division that will be expanded to complete measurement of the division by 2012.

LCRA staff develops accurate field maps for LCRA contracted acreage yearly. The process digitizes into a GIS layer representation of the fields in production each year in an irrigation division and identifies the fields that have been precision leveled through the grant program, their production status, and other water use information.

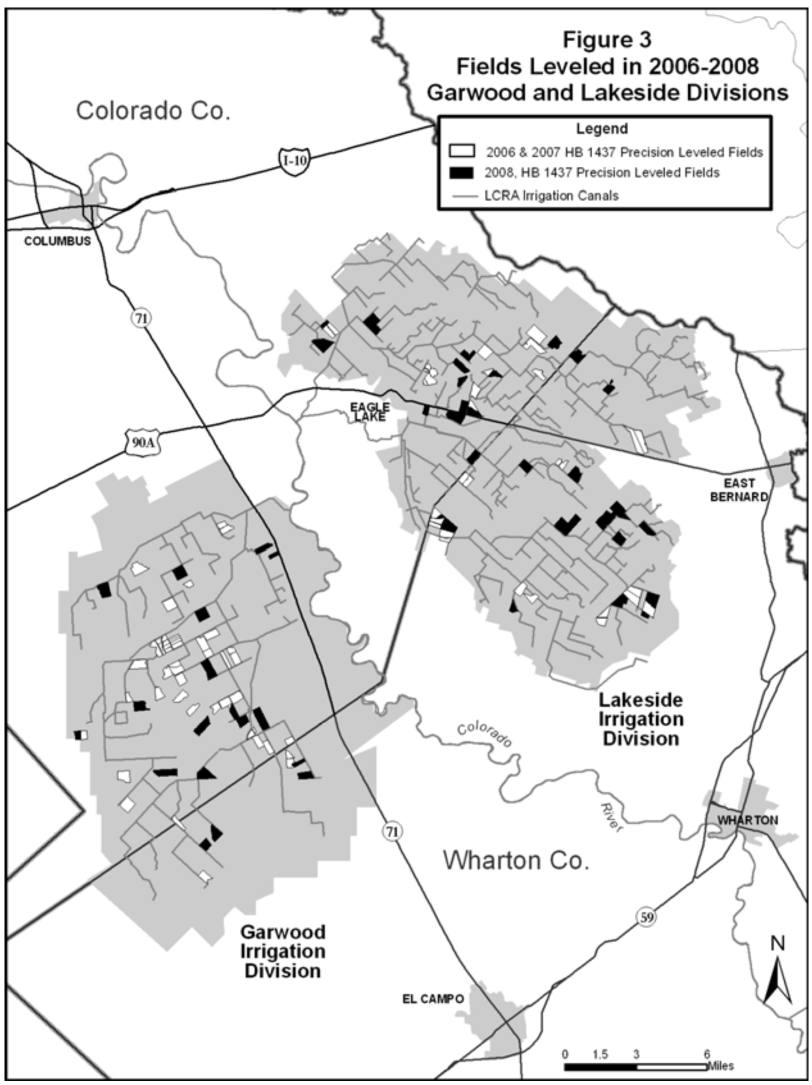


Figure 3. Fields leveled from 2006-2008 in 2 of the 3 irrigation divisions

Water Conserved and No Net Loss

The volume of conserved water produced is calculated by multiplying the number of acres leveled times the conservation factor for precision leveling. Results from field studies at the Texas A&M's Texas Agricultural Experiment Station (TAES) in Eagle Lake support a conservation factor of 0.75 acre-ft of water conserved per acre leveled. A conservation savings verification program is now in progress to refine this conservation factor and the conserved water calculations. To be counted, a leveled field must be in production to receive conservation credit; conservation credit for a fallowed filed is not allowed.

In 2008, an estimated 7,947 acres of HB 1437 fields were in production, conserving an estimated 5,960 acre-feet of agricultural water. This estimate includes current fields and fields previously leveled under the HB1437 program.

No Net Loss Status Table 3 summarizes the 2005-2008 no net loss volume statistics. It shows compliance with the definition of "no net loss" and that a 3-year rolling average of 3,597 acre-feet of HB 1437 water was available for transfer at the end of 2008. To date, no HB 1437 water has been transferred. The entity that was forecasted to need HB 1437 water first canceled its contract with BRA, but there is some indication that negotiations have restarted and another contract could be put into place in the near future.

Table 3. No Net Loss Summary, acre-feet

				Vol. of HB 1437 Water			
Year	Vol. Conserved	Vol. Developed	Vol. Returned	Total Vol. Available	Forecasted Demand	Actual Transferred	Net Loss
2005	0	0	0	0	600	0	0
2006	2,077	0	0	2,077	860	0	0
2007	2,753	0	0	2,753	1,120	0	0
2008	5,960	0*	0*	3,597*	1,380	0	0

* 3-year rolling average

AGRICULTURAL WATER CONSERVATION FUND

The HB 1437 Agricultural Water Conservation Fund (Ag Fund) was established by the HB 1437 legislation and funds LCRA's portion of current water conservation projects. It is an interest bearing, reserve fund recorded in a separate account titled HB 1437 Agricultural Water Conservation Fund. The fund was started in February 2002.

Income to the fund is derived from the annual conservation charge provision incorporated into the HB 1437 water sales contract with BRA. The current charge is 25 percent and is applied to both reserved water and delivered water. Conservation charge income is deposited into the Ag Fund in February of each year. The fund is reduced by HB 1437 program expenditures approved by the LCRA Board and replenished each year with the annual surcharge. Total program expenditures authorized by the LCRA Board through 2008 are $2.025 Million. Figure 4 presents the yearly expenditures, income and balance for the HB 1437 Ag Fund.

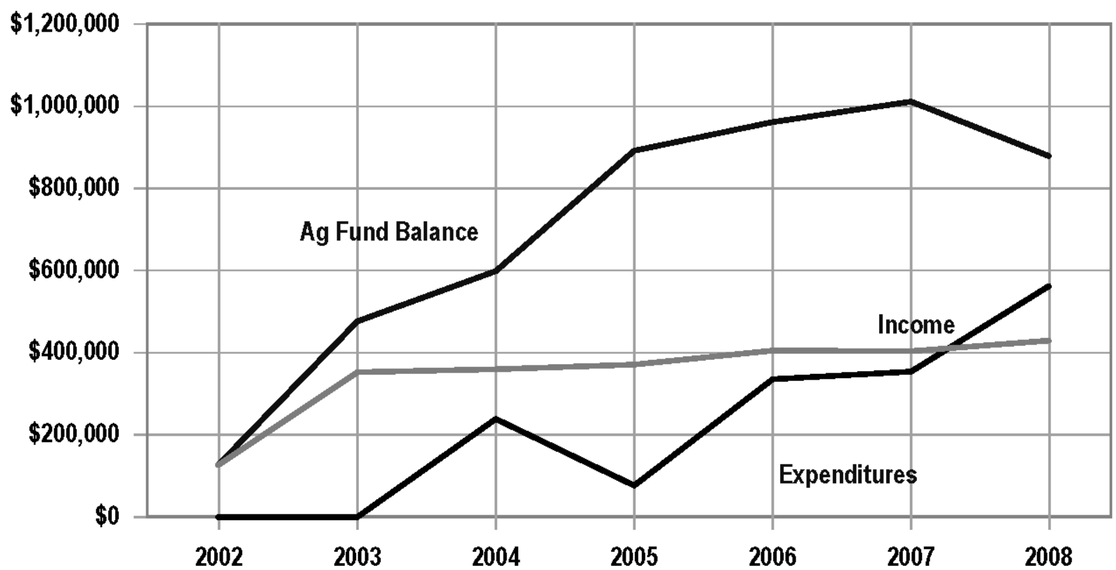


Figure 4. Agricultural Fund Income and Expenditures through December 2008

PROGRAM OUTLOOK

The 2009 program consists of four areas of effort: continue the grant program and cost-share on-farm conservation projects; review and update the HB 1437 implementation plan to account for new demand projections for HB 1437 water; implement and refine the conservation verification program, begin implementation of complete volumetric measurement in the Garwood Division, and meet with the Agricultural Water Conservation Fund Advisory Committee.

2009 Program Activities

The program plan for 2009 consists of grant funded On-Farm Conservation Projects, update of the HB 1437 Implementation Plan, initiation of the in-division Garwood Volumetric Measurement Project, and the LCRA/UT-LBJ Conservation Verification Study.

On-farm Conservation Project In Spring 2009, 6,845 acres were precision leveled through the HB 1437 program. Due to the program popularity and rule changes implemented in late 2008 that established a pro-rated allotment system for the grant money based on a funding cap set by the LCRA board for the current grant funding cycle, LCRA was only able to offer a cost share of 12.5% of the total project costs instead of the 30% cost share offered in previous years.

Results from the first three years of the grant program indicate that the additional cost-share contribution from HB 1437 encourages producers with existing EQIP contracts to complete the contracted work. The lower cost share in 2009 suggests that producers are willing to accept less than a 30 percent cost share.

EQIP remains a popular program for producers due to the availability of funds and its flexible contract terms. Producers holding EQIP contracts are allowed up to 10 years to complete the work. In 2005, NRCS reported that only 10 percent of the awarded EQIP contracts had been completed. This backlog of funded, but uncompleted, projects provided a reservoir of low-cost conservation projects. However, as shown in Table 4, this is changing.

The NRCS reported that, as of March 2009, 78 percent of the awarded EQIP contracts have been completed (up from 50 percent in 2007), and since April 2005, just over 38,000 acres of EQIP contracts have been added. These changes indicate strong support for EQIP and the positive effect HB 1437 is having on the implementation of water conservation projects.

Table 4. Contracted and Applied EQIP Precision Leveling Acreage, as of March 2009

County	Contracted	Installed	Remaining
Colorado	22,648	15,808	6,840
Wharton	14,283	13,021	1,262
Matagorda	1,173	956	217
Total	**38,104**	**29,785**	**8,319**

Implementation Plan Update An engineering study has been completed to update the short term (2010- 2014) implementation plan and reassess the types and timing of new conservation projects. The findings indicate that sufficient funds are available to continue grants for precision land leveling, fund the on-farm volumetric measurement project in Garwood and retrofit 11 check structures in the irrigation divisions. A long-term plan will also need to be developed to meet BRA water demands for the full 25,000 acre-feet/year.

Garwood Volumetric Measurement The Garwood Volumetric Measurement program will implement water measurement structures within the Garwood Irrigation Division. The implementation of volumetric measurement in the Garwood Division is similar to implementation of volumetric measurement in the other LCRA irrigation divisions during the early 1990s.

Not only will the farmers be charged for the amount of water used, which has been shown to result in conservation compared to flat-rate systems, but the Garwood Irrigation Division staff will control the water delivery structures, improving water distribution, improving information for management of flows in the system, and increasing accountability for improved water management by individual farmers. This strategy will improve control of flow in the outer reaches of the Garwood division, particularly in areas where there may be long field laterals, and it includes installation of additional check structures that will provide for improved management and control of water though the canal system.

Conservation Monitoring and Measurement Study In August 2009, LCRA contracted with the LBJ School of Public Affairs at the University of Texas in Austin to conduct a robust statistical analysis of the HB 1437 water conservation program.

Verification of the water savings from HB 1437 program is essential to comply with the "no net loss" provision and accurately judge the efficacy of numerous policies and resources invested in water-conserving programs. An initial look at comparing water use between leveled and non-leveled fields within one crop season indicates that the data is normally distributed, and that there is a statistically significant difference in the water use between leveled versus non-leveled fields. Findings from that analysis also identified the need for future study to: (1) consider multiple years in the analysis; (2) incorporate parameters to extend the statistical analysis to a complete model, reducing or eliminating the effects of confounding factors measured along with the variable of interest (precision laser-land leveling); and (3) account for the lack of independence between observations, which is an assumption required when using the t-test, by specifying a model that incorporates clusters of fields at the farmer/ownership level.

Differences in farmers' skills and practices are one of the many factors that affect on-farm water use. Because initial differences in farmers' management may partially account for later variation in water use, it is critical to disentangle the effects of farm management from the effects of precision laser-land leveling. Only then, can conservation programs be credited with reliable water savings by policy makers and researchers. For instance, farmers who have implemented precision laser-land leveling may use other best management practices or have above average management skills. In sum, it is likely that management skills alone partially explain on-farm water use.

This analysis differs from preceding analyses in that most statistical inferences were made assuming similar management skills across all fields [4]. The LBJ school proposal will use Hierarchical Linear Models (HLM) to sort out the effects of a farmer's management skills across a cluster of fields; in essence to parse out differences in water use attributable to a cluster of fields managed by a single farmer. Using HLM, there are three primary goals: (a) to determine the extent to which precision laser-land leveling explains on-farm water use; (b) to identify other factors that affect water consumption such as temperature, rainfall, duration of crop season, and other water conservation measures in place; and (c) to examine how these factors operate at the field level as well as among groups of fields managed by the same farmer. For instance, different patterns of water use that exist between leveled and non-leveled fields managed by the same farmer can be distinguished. HLM analysis allows for both correlation between observations and correlation through time. These HLM models have several advantages. They will allow comparisons across multiple years, data from all fields are used for calculations (even when each rice field is not in production every year), and the data structure has many more records, making it suitable for small sample sizes.

The purpose of this analysis is to develop a model that tests hypotheses about factors that influence on-farm water use; a model that addresses statistical testing for precision graded verification. In the first model the main effect of precision graded laser leveling will be added (the effect that is of primary substantive interest), then a series of controls will be added (effects we want to remove) and mediating variables (effect we are interested in disentangling from the main effect) will be added last in a stepwise fashion. In this sequence of models, predictors that reflect changing characteristics will be included; for instance, correction for annual climate variation through rainfall and temperature. Length of the growing season will also be included as a variable as well as land ownership, the individual who is farming the land (representing management skills), the number of levees present in each field, and the presence of multiple inlets. The number of levees has been used in previous studies to determine the quality of precision land leveling. Multiple inlets is the practice of releasing water at multiple points along the side of a field utilizing a field lateral and multiple flow control structures instead of feeding all water through the highest section or cut of a rice field and cascading it down through each lower cut to the field outlet.

This analysis will be completed for the Lakeside Irrigation Division in the spring of 2010 with a goal of determining a field-verified conservation factor for that division. This research will be used to measure water savings and could be used to inform the development of guidelines for evaluating water conservation policies. Policy makers and water regulators, such as the LCRA and NRCS, may use the results of this research to evaluate alternative strategic investments in water conservation technologies by comparing water savings and investment costs. The results of this study have important implications to influence the direction of LCRA's future cost-share funds for water-conserving technology.

---

[4] Water Savings Verification and Monitoring Program–2007

In the future, data from the other districts will be evaluated to determine if a similar analysis will work for those divisions given more data limitations in those areas. LCRA has been collecting measured water use from a limited subset of leveled and non leveled fields in the Garwood Irrigation Division for two years, but the sample size is not large enough to run the HLM model described above until more data is available as the Garwood volumetric measurement project progresses. In 2007, LCRA began a pilot project to measure water use of HB1437 fields in Garwood. For the first year, these daily flow measurements proved to be unreliable since adjacent farmers adjusted water flow to their fields between these measurements. In response to this issue, in 2008, LCRA started controlling and measuring a small subset of the irrigation division, requiring producers to contact LCRA to take water. This pilot program was continued in 2009 to accurately measure about 1,600 leveled and unleveled fields. This program will be rolled into the project to measure all on-farm water use by 2012 and will eventually enable LCRA to run this statistical model for the Garwood Division. This statistical model cannot be applied to the Gulf Coast Irrigation Division at this time either because of the low participation in the HB 1437 grant program and therefore the low sample size of leveled fields. In future years, LCRA will focus more efforts on investigating roadblocks to participation in that division such as different EQIP priorities than the other counties.

Program Oversight and Communication A large part of the HB 1437 implementation study was a public input process to involve various stakeholders in the framework and conservation strategies of the HB 1437 program. Since the grant program began in 2006, yearly updates have been provided about the program to farmers through annual farmer advisory meetings in each division and individual contact with division staff. The 2008 HB 1437 annual report is available on LCRA's website, and staff will continue to update the website as a part of on-going conservation communication efforts. The 2009 annual report will be available in April 2010.

In 2009, staff worked with key local producers to reappoint members of the Ag Advisory Committee members through county judges. This committee has reconvened, is providing guidance on the conservation verification study, and will be involved in the long term plan. In November 2009, this committee recommended that LCRA pursue a detailed survey of Lakeside contract holders to gather more information about additional factors that affect water use but are not currently collected by LCRA. These factors include additional conservation measures such as multiple inlets, conservation tillage, and permanent perimeter levees, details about the slope, type of levee and levee density to determine quality of land leveling, rice variety, and ownership stake. These variables will be included as part of the HLM model.

LCRA is in the process of developing an oversight committee composed of several academic and policy experts in statistics and agricultural conservation practices for this verification study. Feedback and endorsement of methodology from this committee will be important to obtaining widespread acceptance of the results of this study.

Future Challenges

While this program shows much promise, it is still relatively new and has not yet been completely tested since no water has been transferred. Participation in the grant program has exceeded LCRA's expectations and the relationship with NRCS has been beneficial for both parties by reducing costs for LCRA and increasing the pace of contract completion for NRCS.

Future challenges include the development of a long-term plan that addresses the one-to one replacement policy and the issue of water availability during periods of drought. LCRA accounts for the water saved in this program as "interruptible" water meaning it can be cut off during times of drought, yet delivers the water to Williamson County as "firm" water, meaning it is water guaranteed during drought.

REFERENCES

Agarwal, MC, and Goel AC. (1981). "Effect of field leveling quality on irrigation efficiency." Agricultural Water Management 4(4): 457-464.

Anderson, David P., and Thompson, Gary D. (1999). "Adoption and Diffusion of Level Fields and Basins." Journal of Agricultural and Resource Economics 24(1): 186-203.

Bjornlund H, Nicol L, and Klein KK. (2009). "The adoption of improved irrigation technology and management practices-A study of two irrigation districts in Alberta, Canada." Agricultural Water Management 96(1): 121-131.

Smith, M.C.; Massey, J.H.; Branson, J.; Epting, J. W.; Penington, D.; Tacker, P.L.; Thomas, J.; Vories, E.D.; and C. Wilson. (2007). "Water use estimates for various rice production systems in Mississippi and Arkansas." Irrigation Science. 25: 141-147.

MARKETING AND FINANCING A WATER BANK: "FIRST GET YOUR HOUSE IN ORDER"

David Dorrance[1]
Andrew Werner[2]
Wilmar Boschman, PE[3]

ABSTRACT

Water banks entail the recharge of periodically available excess surface water for storage underground and recovery when needed. Properly formulated, these projects are one of the most cost-effective water supply tools available. These projects are frequently located in rural areas due to availability of land and water. However, projects with capital programs of more than $10 million typically need to be funded with financing. Traditional financing mechanisms such as raising customer fees, bonding and state/federal grants are increasingly difficult to obtain. Therefore, many rural agencies pursue partnerships with urban water utilities that typically have more available capital. This approach, pioneered by Semitropic Water Storage District and Arvin-Edison Water Storage District in the 1990s, entails upfront payments (and annual operating fees) by the utilities in exchange for long-term leases of project capacity. The decision to use this funding approach must be made early in the project formulation because it requires that the project be sized and configured to meet both local and utility partner needs. Water utilities are only willing to enter into these partnerships if the project can increase their water supply reliability at a lower cost than other alternatives and only if three critical criteria have been met: 1) Lack of controversy as evidenced by tangible benefits to, oversight from and support by local stakeholders; 2) proven technical, regulatory and economic viability; and 3) operational flexibility and modularity, enabling construction in phases. A project should not be marketed before each element is in place. These requirements typically take several years and several million dollars to achieve.

INTRODUCTION AND BACKGROUND

Western Development and Storage (WDS) is a consultant to the Semitropic Rosamond Water Bank Authority (SRWBA), a joint power authority (JPA) that manages 800,000 acre-feet (AF) of water banking projects in the Central Valley and the Antelope Valley of California. The SRWBA program includes over $300 million in capital projects that are in various stages of planning, construction and operation. WDS works with GEI Consultants (GEI) to help the JPA fund these projects through a variety of means that include marketing of capacity to third parties; grants; and contributions by JPA members. This paper summarizes key lessons learned from these efforts.

---

[1] Vice President, Western Development and Storage, Los Angeles, CA, davedorrance@westerndev.com
[2] Vice President, Western Development and Storage, Los Angeles, CA, andrewwerner@westerndev.com
[3] General Manager, Semitropic Rosamond Water Bank Authority, Wasco and Rosamond, CA, wboschman@semitropic.com

The SRWBA was formed by Semitropic Water Storage District (Semitropic), Rosamond Community Services District (RCSD) and Valley Mutual Water Company (Valley Mutual) in 2007 as a Joint Powers Authority to construct, manage and operate a portion of the Semitropic Stored Water Recovery Unit (SWRU) near Bakersfield, CA and the Antelope Valley Water Bank (AVWB) near Rosamond, CA. These projects provide 800,000 AF of storage, up to 330,000 AF/year of recharge and 200,000 AF/year of recovery. The JPA is also participating in other projects that will create over 200,000 AF/year of new water supplies. Figure 1 depicts the locations of SRWBA projects.

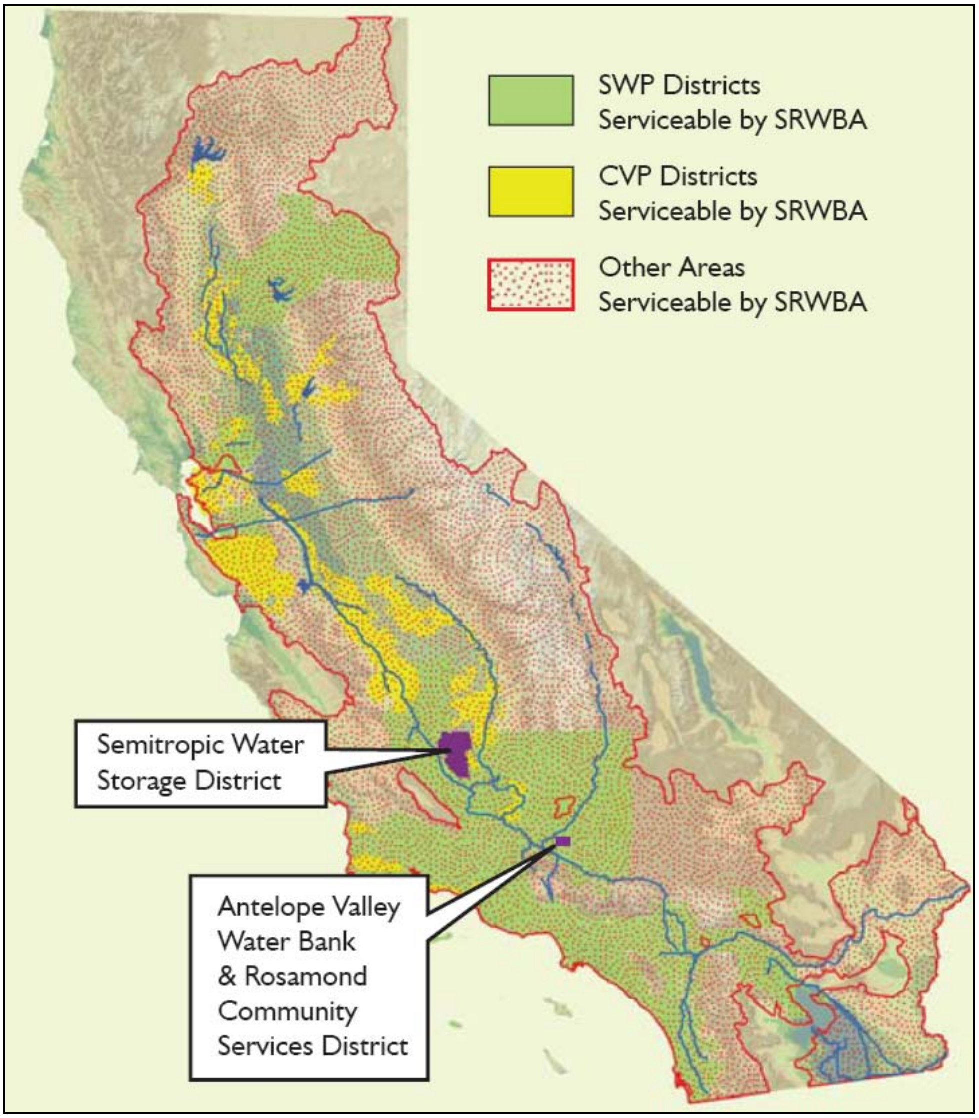


Figure 1. SRWBA Location Map

Water banks are inexpensive relative to other storage alternatives. Peterson (2009) and Hanak (2005) indicate that conservation, reservoirs, wastewater recycling and desalination can respectively be 5, 9, 12 and 18 times more expensive. As with most water banks, the JPA's projects recharge periodically excess surface water into partially depleted aquifers for storage underground until needed. Recharge is performed using percolation basins and the in-lieu method (delivery of surface water to farmers in-lieu of normal groundwater pumpage) that was pioneered by Semitropic in the 1990s. Water is recovered using a combination of new and existing wells that pump into new and existing conveyances. The first phases have been constructed and work is proceeding on the next phases. The JPA has designed the projects to serve local needs, but has sized them to also enable participation by out-of-basin entities that are willing to make payments that help fund construction. Over the last 18 years Semitropic, an agricultural entity, has successfully used this approach to finance facilities that have banked over 1.2 million AF, mostly for urban agencies. For marketing purposes, capacity in the SRWBA water banks have been allocated into 200,000 "shares", with one share defined as follows:

- 0.33 AF/year (SWRU) to 1 AF/year (AVWB) of recharge capacity;
- 3 AF (SWRU) to 5 AF (AVWB) of storage space;
- 1 AF/year of recovery capacity; and
- Access to additional capacity when it is not being used by others.

The JPA is not issuing bonds and JPA members are not raising rates. Rather, the capital program is being successfully funded through three means: 1) Direct payments by JPA members from cash reserves; 2) Various grants; and 3) Upfront capital payments by contract participants. There is considerable uncertainty in the timing of these funding sources. Therefore, the JPA's projects are modular (i.e. fully operational units) so they can be constructed in phases that match the flow of funds. Capacity is offered to contract participants under the following terms:

- Upfront capital fee for facilities construction (fee reduced for larger share blocks);
- Annual management fees (escalated with the consumer price index, CPI);
- Recharge fee (escalated with CPI);
- Recovery fee (escalated with CPI) plus actual energy costs;
- Access to additional project capacity when it is not being used by others;
- 10% of all recharged water left behind to benefit the local aquifers;
- Term: through 2035 (expiration date of State Water Project Contracts, which are expected to be renewed); and
- Costs to procure and convey water to/from the project carried by the participant.

This structure is straightforward and if a sufficient number of shares are contracted, it can eliminate the need for construction financing. However, it has been the authors' experience that potential participants will not execute contracts unless the project has met three criteria: 1) Lack of controversy as evidenced by tangible benefits to, oversight from and support by local stakeholders; 2) proven technical, regulatory and economic viability; and 3) operational flexibility and modularity, enabling construction in phases.

THE SRWBA EXPERIENCE

This paper summarizes key lessons learned from the circumstance of a multi-million dollar project in a primarily rural area that will tie new facilities to existing regional conveyances within a basin that has chronic swings in water availability and with numerous stakeholders whose interaction has been marked by on-going controversy and sporadic consensus. A stakeholder refers to a person or entity that could benefit or be harmed by the project, including: surrounding land owners; nearby water agencies; nearby groundwater pumpers; nearby municipalities; farming interests; county departments, the regional air and water boards; governmental and non-governmental wildlife organizations, and state and federal agencies. Finally, it is assumed that the project requires preparation of an environmental impact report (EIR) under the California Environmental Quality Act (CEQA) or an environmental impact statement (EIS) under the National Environmental Policy Act (NEPA).

STAKEHOLDER OUTREACH: MEANINGFUL, EARLY AND ON-GOING

Following the adage, "first get your house in order," a project should not be marketed to potential out-of-basin participants until local stakeholders have been thoroughly consulted and included in the project. Semitropic was required to give local agencies a first right of refusal for any capacity. Sizable water banks impact groundwater levels and quality beneath large areas that may not be entirely controlled by the proponent. While California case law clearly supports the right of a water bank to recharge and recover water as long as it is not to the detriment of others, the proponent must be sensitive to the fact that underground storage space and groundwater are shared resources. As a consequence, stakeholders must be part of the planning and oversight of these projects. Many water bank proponents make the mistake of limiting stakeholder involvement to the public scoping and review processes that are required under CEQA and NEPA. This is not sufficient and generally generates distrust amongst stakeholders because the distributed materials typically make it clear that significant planning and expenditures have already gone into the proposed project without their involvement.

Stakeholder involvement and support are essential to project funding. Most grant programs and potential utility participants require demonstration of support. These requirements have arisen because past programs became mired in controversy due to lack of meaningful outreach by the project proponent. Stakeholders can prevent a project from proceeding in a variety of ways that include: 1) Raising objections during the CEQA/NEPA processes; 2) Filing law suits; 3) Gaining the support of key board members that vote on project actions; 4) Running opposition candidates during elections for board seats; and 5) Gaining publicity that scares away potential participants.

Meaningful stakeholder outreach not only minimizes opposition, but benefits the project by improving the project formulation and opening up new avenues for marketing.

Include stakeholders in project formulation early: Key stakeholders should be consulted early in project formulation to better define the need and areas of likely controversy. If performed in an open, honest fashion, this consultation benefits the project in two ways: 1) It invariably results in new ideas that influence the project configuration; and 2) It establishes lines of communication that are valuable during later stages of the project when controversies may evolve. For example, several proposed projects included plans for "borrowing" water from the aquifer, with the "borrowed" water to be returned during future recharge operations. While this concept might have been technically sound, it was opposed by stakeholders to the degree that the proposed projects were halted. If more thorough stakeholder consultation had occurred, the projects might have been reformulated and millions in wasted expenditures may have been avoided.

Provide tangible benefits to the local basin: It is not sufficient to simply prevent harm to surrounding stakeholders. The basin must also gain tangible benefits from use of the shared aquifer. Most water banks donate a portion of imported surface water to the basin (typically from 5% to 15%), resulting in an accumulation of water in the aquifer that would occur only with the presence of the project. There are a variety of additional benefits that can be incorporated into project (several of which can also provide funding opportunities), including: upgrades to existing water and power infrastructure; providing stakeholder access to new pipelines, canals and wells when not required by the project; operation of basins to aid flood control; farming in recharge basins when not being used by the project; stakeholder access to imported water supplies that periodically become available above project needs; broadening of local groundwater monitoring programs; procurement and hiring practices that support woman and minority owned businesses and provide training to locals; and reduction of surface water treatment costs.

The last item, reduction of treatment costs, deserves some explanation. Over 30% of surface water treatment cost is associated with removal of suspended solids from the raw water. Water banks located near utilities that operate these treatment plants are presented with an opportunity to dramatically reduce the utility's treatment costs by substituting water recovered from the water bank for raw surface water. This is because water banks typically percolate raw water into storage through sands and gravels that remove the majority of suspended solids and the projects then recover the water from wells that have been constructed to meet health standards. As a consequence, water recovered from a bank requires significantly less treatment than raw water usually received by the utilities. While the recovered water is typically not yet potable and still requires treatment, this de-facto "pre-treatment" can be of significant benefit to the surrounding water utilities.

Perform meaningful CEQA and NEPA analysis before expending significant funds on land and detailed design: Stakeholders justifiably distrust any effort in which the proponent agency has already "locked-in" the project before the environmental analysis has been performed.

Have reliable, open and on-going representation at all major stakeholder functions: Water banks permanently change the way a groundwater basin is managed. Therefore, stakeholders deserve regular availability of a knowledgeable project representative who can provide progress reports, answer questions and obtain invaluable feedback. This is essential in basins where there are nearby groundwater pumpers and other water banks. Simply holding periodic "open houses" or devoting a portion of each board meeting to the project is not sufficient. The project must go out into the community and provide recognizable faces that can be approached in a variety of forums on a regular basis. This can easily become a full time job. SRWBA representatives attend dozens of regularly scheduled meetings that include: stakeholder board meetings, farm bureau meetings, various industry association meetings, town hall meetings and various open houses.

Recognize that there is uncertainty, provide meaningful local oversight and pre-defined mechanisms for prevention of and response to unacceptable impacts: By their nature, water banks have uncertain performance and impacts. While modeling and pilot testing are essential parts of project planning, the proponent should not try to convince stakeholders that they will not be impacted based on model or pilot test results. In fact, all water banks have potential impacts that cannot be fully assessed until the project has been built and there have been several recharge and recovery cycles. A great deal of goodwill, time and money can be wasted if the project devolves into a fight with stakeholders over the interpretation of model and pilot test results. Conversely, stakeholders embrace an approach in which uncertainty is recognized and addressed through a monitoring and operational constraint program (MOCP) developed by a committee that includes stakeholders. A typical MOCP includes: monitoring locations and parameters; protocols for dissemination of information to stakeholders; protocols for constraint of operations if data indicate an unacceptable impact may occur; a process for filing and objectively reviewing complaints; and a process for determining appropriate mitigation measures in the event it is concluded that an unacceptable impact has occurred. The key is to provide stakeholders with a clearly defined process through which problems can be fairly resolved. This process is simplified by the fact that unacceptable impacts are most likely to occur near recovery wells and nearby stakeholder wells – which are clearly defined locations that are easily monitored.

PROVEN TECHNICAL, REGULATORY AND ECONOMIC VIABILITY

Potential project participants and grant agencies are increasingly requiring the following work before they will invest in a project.

Proof of Performance: Potential participants consistently require site specific investigations that demonstrate there are no fatal flaws and that the marketed capacity can be achieved. Commonly required testing includes: trenching, borings, percolation tests, leaching tests, surface water and groundwater compatibility tests, geophysical surveys and long-term recharge tests. As previously mentioned, there must be a MOCP to mitigate unacceptable impacts. Depending on the size of the project, this work can take several years and usually costs from $500,000 to $2 million.

Regulatory Compliance: Potential participants and grant agencies frequently require CEQA and NEPA compliance prior to making project payments. The proponent is usually required to carry these regulatory compliance costs. Potential participants impose this requirement not only to ensure that the project can be executed promptly, but also because they know that the CEQA and NEPA processes spotlight any stakeholder opposition or flaws that could cripple the project. Depending on the complexity of the project, this work typically takes several years and costs from $250,000 to $2 million.

Financial Viability: Potential participants will only invest in a project if it will be more cost effective than other alternatives such as competing water banks, surface reservoirs, periodically buying water on the "spot" market, acquiring new water rights, wastewater reuse, conservation and desalination. This is a complicated comparison that must take into account variations in reliability, cash flow and costs outside of the project such as water procurement and wheeling of water to and from the project. Potential participants are typically not sufficiently familiar with water banks to adequately evaluate project life cycle costs. Conversely, project proponents are usually not sufficiently familiar with the potential participant's costs or financial criteria to prepare a useful analysis. Taken together, the project proponent should be prepared for a multi-month process in which they will submit capital and operating cost estimates to the potential participant, which will then perform the cost-benefit analysis. This is an iterative process that can become frustrating, but it affords an opportunity to build working relationships and trust.

MODULARITY AND OPERATIONAL FLEXIBILITY

As previously indicated, no matter how much investigative work has been performed, there is always significant uncertainty regarding water bank performance. There is additional uncertainty with the operations that surround a water bank, including: timing, volumes and quality of water to be banked and recovered; availability of wheeling capacity in 3rd party conveyances; and power costs at the time of recovery. In the face of these uncertainties, it is unwise to fully build out a recharge and recovery system in one phase. Experience has shown that these projects should be built adaptively, with the performance of each phase evaluated to determine how the design of future phases should be adjusted to attain the required capacities. Because a recharge and recovery cycle can span several years, this adaptive approach results in construction programs that can spread over 5 to 15 years with operational cycles and design adjustments interspersed. In anticipation of inevitable unexpected operational results, potential participants look for water bank projects with the following characteristics:

- At least two alternate ways in which water can be conveyed to and recovered from the facility;
- Complete project control of at least one pipeline or canal that ties to regional conveyances;
- At least 25 percent excess land (or in-lieu pumper demand) for recharge; and
- An ability to build fully functional modules in phases.

In short, potential participants are hesitant to invest in projects that unduly rely on a single facility could be shut down by operational, political or regulatory developments.

PROJECT DEVELOPMENT FUNDING GAP

As detailed in previous sections, most sizeable water banks require years, thousands of man hours and millions of dollars before they can have a reasonable chance of securing financing. Assuming that they do not raise rates, most rural water agencies lack the cash flow, time and expertise to pursue these efforts. Planning grants are increasingly difficult to obtain. As a result, good projects languish and poorly thought out projects are prematurely marketed. There is no single solution to this funding gap, but the following are some examples of how it is being addressed.

Use of cash flow and available staff: Most districts have discretionary cash reserves. If the need for a water bank is sufficiently acute, some districts have funded early efforts from these reserves. Most districts that serve farmers have reduced demand on staff time during the non-irrigation months. Some districts use these staff and district equipment to perform early work and investigations. The results of this approach are mixed, depending on the available expertise.

Increased new customer connection fees: Several districts have imposed significant fees on new customers, with the generated funds used to pursue water bank initiatives.

In-kind contributions by consultants: Some districts enter into agreements with consulting firms that contribute their expertise at reduced rates in exchange for future project work. These arrangements require careful consideration of competitive bidding requirements.

Investment by private developers: Some districts enter into agreements with developers (power, real estate, dairy, biofuels and others) that contribute funds in order to reserve capacity for their needs should the project succeed.

Monetization of excess land controlled by the district: Many districts hold land that is not required for normal operations or the project. Some districts have sold or leased these lands to various solar, wind, biofuels and real estate developers.

KEY LESSONS LEARNED

In summary, the key project components that are inexorably linked to successful marketing and financing of a water bank include:

- Projects that propose to "borrow" water from the aquifer before recharge has occurred and projects that export native water from the basin are usually, "dead on arrival";
- Decide on the financing approach early because it impacts project formulation;
- Be open, inclusive and provide benefits to stakeholders;
- Confront operational uncertainty head-on by putting in place response procedures, redundancy and optionality;
- Do not market outside the basin until local stakeholder support is obtained;
- Do not market capacity until adequate testing has been performed; and
- Be prepared to carry upfront investigative and permitting costs for several years.

Finally, a project proponent should not underestimate the amount of time it takes to market, negotiate and contract water banking agreements. In most cases, at least a year is required from the initial expression of interest through the execution of contracts.

REFERENCES

Hanak, Ellen, "Water for Growth, California's New Frontier," 2005, Public Policy Institute of California, 196 pp.

Peterson, C, "Groundwater Storage and Conjunctive Use in California, Opportunities and Considerations," 2009, MWH, Proceedings of Water Transfers and Supply Development: Meeting California's Growing Water Needs, 30 pp.

IMPERIAL IRRIGATION DISTRICT IRRIGATION SCHEDULING AND EVENT MANAGEMENT PILOT PROGRAM

Darren R Fillmore[1]
Byron Clark, P.E.[2]
Grant G. Davids, P.E.[3]
John R. Eckhardt, Ph.D., P.E., P.H., D.WRE[4]

ABSTRACT

The Imperial Irrigation District (IID) administered a pilot program in 2008 and 2009 to test various concepts proposed to fulfill its on-farm water conservation obligations under the Quantification Settlement Agreement. The program was intended to conserve about 1,000 ac-ft of water for payback of IID's Inadvertent Overruns in accordance with the Colorado River Water Delivery Agreement.

Growers were invited to implement irrigation scheduling and event management for six months to conserve water relative to an ET-normalized, crop- and field-specific, historical water use baseline. Participants were required to hire an IID-qualified firm to provide irrigation scheduling and management recommendations, though they were not obligated to implement those recommendations. Upon enrollment, participating growers received a payment to fund a contract with a scheduling firm and to help defray some irrigation management costs. After the contract period, eligible participants received an additional payment based on the volume of water conserved.

The program resulted in water savings of 0.1 – 1.2 ac-ft/ac on most of the 24 enrolled fields, though some fields used more water than their estimated, historical baseline.

BACKGROUND AND OVERVIEW

The Imperial Irrigation District (IID) in southeast California diverts approximately 3.1 million ac-ft of Colorado River water annually to irrigate approximately 475,000 ac of agricultural lands. In 2003, IID entered the Quantification Settlement Agreement and Related Agreements (QSA), agreeing to the transfer of 303,000 ac-ft annually to other Colorado River water users in California through conservation projects aimed at increasing on-farm irrigation efficiency and distribution system efficiency. As a condition of the agreements, at least 130,000 ac-ft must be generated through the implementation of on-farm conservation measures (CMs).

[1] Irrigation Engineer, Imperial Irrigation District, P.O. Box 937, Imperial, CA 92251, 760-339-9784; drfillmore@iid.com
[2] Project Manager, Davids Engineering, Inc. 1772 Picasso Avenue, Suite A, Davis, CA 95618, 530-757-6107; byron@de-water.com
[3] President, Davids Engineering, Inc. 1772 Picasso Avenue, Suite A, Davis, CA 95618, 530-757-6107; grant@de-water.com
[4] Executive Program Manager, QSA-IID/SDCWA Water Transfer, Imperial Irrigation District, P.O. Box 937, Imperial, CA 92251, 760-339-9737; jreckhardt@iid.com

In 2007, IID completed its Efficiency Conservation Definite Plan (Plan), which identifies the most cost-effective mix of on-farm and system improvements needed to satisfy transfer obligations while keeping expenditures below available transfer revenues. On-farm participants in the transfer program will be provided incentives to implement CMs to achieve conservation goals. The Plan identified numerous CMs that growers are likely to consider. Among those CMs growers expressed interest in implementing were management-based CMs aimed at increasing irrigation efficiency through decreased tailwater production including irrigation scheduling and event management.

In particular, interest was expressed in improving surface irrigation methods through irrigation scheduling and event management. Scientific Irrigation Scheduling (SIS), as evaluated under the Plan, includes decisions made prior to placing irrigation orders for individual fields including the timing, duration, and amount of water aimed at minimizing tailwater production while satisfying crop water requirements. Scientific Event Management (SEM), as evaluated under the Plan, includes decisions made after the start of an irrigation event based on observed advance, infiltration, and runoff aimed at minimizing tailwater production while providing adequate infiltration to meet crop water needs. An emphasis on event design is needed because flexibility in irrigation timing is limited due to cropping practices, particularly for forage crops (alfalfa, Bermuda grass, Sudan grass, etc.).

In 2008, IID implemented the Irrigation Scheduling and Event Management Pilot Program (Program) to test various aspects of the on-farm program including enrollment, verification of conserved water, and conservation potential. In addition to testing various aspects of the longer-term, on-farm efficiency conservation program under consideration by IID, the Program provided growers an opportunity for early implementation of conservation measures.

PROGRAM DESIGN AND IMPLEMENTATION

The Program was implemented between mid-2008 and mid-2009 with fields typically enrolled for a six-month period. As a voluntary program, owners and lessees of eligible fields were invited by IID to participate in the Program through a newspaper advertisement. Interested growers participated in a consultation with IID staff to establish eligibility and to discuss Program details. Those growers ultimately wishing to enter the Program entered into a contract with IID under which they were required to hire a qualified irrigation management consultant to provide recommendations regarding the scheduling, design, and management of irrigation events. Irrigation management consultants were screened for qualifications by IID prior to the start of the Program.

The following eligibility requirements were applied to help achieve water conservation targets, reduce costs, and ease program administration and verification:

- Fields were required to be at least 65 ac
- Where one gate served multiple fields, all fields were required to enroll

Participating growers received payment based on (1) participation in the Program and (2) the amount of water conserved. An initial payment of $4,000 per field was made to reimburse the grower for the cost of hiring an irrigation management consultant. A final payment was made based on the verified conserved water (determined as described below) This payment was intended to provide incentive to conserve water through efficiency improvements and to provide reimbursement for the anticipated increase in on-farm labor and management costs associated with the Program. Fields conserving at least 0.2 ac-ft/ac received a final payment of $45/ac-ft. The final payment was limited to $45/ac (i.e., 1.0 ac-ft/ac) to discourage conservation by deficit irrigation.

Following completion of the Program, both growers and consultants were asked to provide feedback to IID to assist in planning future on-farm efficiency conservation programs.

OUTCOME

Enrolled Fields

Twenty-four surface-irrigated fields representing 2,754 ac were enrolled in the Program. The most commonly enrolled crop was alfalfa (2,076 ac). Other crops included wheat (311 ac), sugar beets (223 ac), and citrus (144 ac).

Perennial crops (alfalfa and citrus) were enrolled for exactly 6 months. Annual crops (wheat and sugar beets) were enrolled for the length of the crop season. Start and end dates for each field are listed in Table 1.

Irrigation Management Consultants

Interested consultants were required to submit qualifications to IID. IID evaluated consultant responses, conducted interviews, and selected approved consultants for the Program. Consultants were evaluated based on their experience, references, qualifications of key individuals, availability of irrigation scheduling software, and availability of key personnel within the Imperial Valley. Two irrigation consultants were selected: JMLord, Inc. of Coachella (www.jmlordinc.com), and Stanworth Crop Consultants, Inc. of Blythe (www.stanworth.net).

The irrigation management consultants were required to provide the following services under the Program:

1. Develop written irrigation recommendations based on a daily root zone water balance, including quantification of crop evapotranspiration (ET) and regular updates based on field observations of soil moisture content.
2. Conduct regular field visits to evaluate soil moisture content, percent ground cover, crop growth stage, and other indicators of crop ET.
3. Evaluate at least one irrigation event based on procedures of the NRCS National Irrigation Guide.

4. Provide a brief post-season report providing observations regarding the extent to which the grower adopted recommendations or otherwise modified practices, physical limitations of the field limiting water conservation potential, and recommendations for broader implementation of improved irrigation management in the District.

Table 1. Enrolled Fields.

Field	Crop	Irrigation Method	Acres	Start Date	End Date
A	Alfalfa	Graded Border	244.8	22-Sep-08	22-Mar-09
B	Alfalfa	Graded Border	73.2	2-Sep-08	31-Dec-08
C	Alfalfa	Graded Border	75.3	2-Sep-08	31-Dec-08
D	Alfalfa	Graded Border	65.5	2-Sep-08	31-Dec-08
E	Alfalfa	Graded Border	143.9	2-Sep-08	31-Dec-08
F	Alfalfa	Graded Border	70	13-Nov-08	13-May-09
G	Alfalfa	Graded Border	75.1	13-Nov-08	13-May-09
H	Alfalfa	Graded Border	73.2	13-Nov-08	13-May-09
I	Alfalfa	Graded Border	72.6	13-Nov-08	13-May-09
J	Alfalfa	Graded Furrow	148	15-Sep-08	15-Mar-09
K	Alfalfa	Graded Furrow	144	15-Sep-08	15-Mar-09
L	Alfalfa	Graded Furrow	145	5-Sep-08	5-Mar-09
M	Alfalfa	Graded Border	127.8	18-Aug-08	18-Feb-09
N	Mixed Citrus	Graded Border	144	21-Aug-08	21-Feb-09
O	Alfalfa	Graded Furrow	89	15-Sep-08	15-Mar-09
P	Alfalfa	Graded Furrow	78	15-Sep-08	15-Mar-09
Q	Wheat	Graded Border	91.5	21-Dec-08	1-Jul-09
R	Sugar Beet	Graded Furrow	71.6	10-Oct-08	31-Jul-09
S	Wheat	Graded Border	78.5	21-Dec-08	25-May-09
T	Wheat	Graded Border	140.5	5-Jan-09	26-May-09
U	Sugar Beet	Graded Furrow	151.3	23-Sep-08	4-May-09
V	Alfalfa	Graded Furrow	210.5	3-Sep-08	3-Mar-09
W	Alfalfa	Graded Furrow	172.1	3-Sep-08	3-Mar-09
X	Alfalfa	Graded Furrow	68.2	3-Sep-08	3-Mar-09

Conserved Water Amounts

Conserved water for each field was calculated by first estimating the historical deliveries for the period of 1998-2005 to the enrolled crop at each field (DW_{hist}) along with the historical crop ET, net of effective precipitation (ET_{hist}). Then, the Payment Benchmark (*PB*) was determined as the expected deliveries to the enrolled field without conservation in place. The *PB* was determined based on DW_{hist}, ET_{hist}, and the crop ET net of effective precipitation during the enrollment period ($ET_{current}$) as described in Equation 1.

$$PB = DW_{hist} \frac{ET_{current}}{ET_{hist}} \qquad [1]$$

Thus, the Payment Benchmark was determined by normalizing historical deliveries to the field based on differences in crop ET between the historical and current periods.

The actual Delivered Water Reduction (*DWR*), or conserved water amount, was determined as the difference between the PB and the actual deliveries during the enrollment period ($DW_{current}$), as shown in Equation 2.

$$DWR = PB - DW_{current} \qquad [2]$$

DW_{hist}, *PB*, $DW_{current}$, and calculated *DWR* for each field are provided in Table 2.

Table 2. Conserved Water Estimates for Enrolled Fields (ac-ft/ac).

Field	Crop	Acres	DW_{hist}	*PB*	$DW_{current}$	*DWR*
A	Alfalfa	244.8	3.2	3.4	4.0	-0.6
B	Alfalfa	73.2	1.5	1.6	1.7	-0.1
C	Alfalfa	75.3	1.5	1.7	1.4	0.3
D	Alfalfa	65.5	1.5	1.6	1.5	0.1
E	Alfalfa	143.9	1.4	1.5	2.1	-0.6
F	Alfalfa	70.0	2.0	2.2	2.6	-0.5
G	Alfalfa	75.1	2.3	2.4	2.5	-0.2
H	Alfalfa	73.2	2.0	2.1	2.7	-0.6
I	Alfalfa	72.6	2.1	2.3	3.9	-1.6
J	Alfalfa	148.0	2.3	2.5	1.9	0.7
K	Alfalfa	144.0	3.1	3.0	2.4	0.6
L	Alfalfa	145.0	2.7	2.9	2.0	0.9
M	Alfalfa	127.8	2.7	2.7	2.9	-0.1
N	Mixed Citrus	144.0	3.4	3.6	2.4	1.2
O	Alfalfa	89.0	2.6	2.8	1.9	0.9
P	Alfalfa	78.0	2.8	2.9	1.8	1.1
Q	Wheat	91.5	4.5	4.5	3.9	0.6
R	Sugar Beet	71.6	6.3	9.2	8.4	0.8
S	Wheat	78.5	2.9	3.5	3.5	-0.1
T	Wheat	140.5	2.5	2.9	2.4	0.5
U	Sugar Beet	151.3	5.2	3.8	3.6	0.2
V	Alfalfa	210.5	2.7	2.9	2.3	0.6
W	Alfalfa	172.1	2.5	2.8	2.2	0.6
X	Alfalfa	68.2	2.6	2.9	2.7	0.1

As indicated in Table 2, water savings occurred on 15 of the 24 fields, ranging from 0.1 to 1.2 ac-ft/ac. The area-weighted average of those positive *DWR* values was 0.6 ac-ft/ac and total volumetric savings were 1,133 ac-ft.

The delivered water during the enrollment period was more than the estimated Payment Benchmark for 9 of the 24 fields. An increase in water deliveries to some fields was not unexpected because it is recognized that some fields have historically been deficit irrigated using customary methods of irrigation scheduling. Thus, when using scientific irrigation scheduling, increased water deliveries relative to a historical benchmark may indicate a history of deficit irrigation. On such fields, increased deliveries do not necessarily correspond to decreased irrigation efficiency.

Grower and Consultant Observations

As part of their contract with IID, Growers agreed to participate in a post-season interview. They also agreed to require in their contracts with consultants that consultants provide IID with brief reports during and following the conservation period.

Most growers agreed that they would like to participate in similar future programs and recommended that any future program be timed to allow enrollment of a broader range of crops. Similarly, several growers recommended that the conservation period should be no less than one year to provide a more representative study of perennial crops.

Growers who conserved water under the Program as well as those who did not commented that they changed their irrigation practices as a result of participation. One grower said, “I bought a soil probe to better monitor penetration problems.” Another commented, “We now irrigate our alfalfa less frequently.”

As anticipated, hay cutting schedules proved to be a significant constraint to irrigation timing. As a result, consultants focused on adjusting event design parameters. One consultant remarked, “We improved uniformity by modifying the shutoff time.” Another consultant helped a grower improve distribution uniformity on a sandy, border-irrigated field. He said, “The recommendation was to increase the flow rate on the set in order to move the water more quickly along to the end of the set and thus overcome the higher soil intake rate.” Both consultants noted that growers were very cooperative and eager to make changes that seemed practical for their operations.

DISCUSSION AND CONCLUSIONS

In addition to demonstrating advantages and disadvantages of irrigation scheduling and event management as a conservation measure, the Program provided useful insight about the solicitation and contracting processes, eligibility requirements, grower preferences, baseline estimation, conservation verification, and other aspects of implementing on-farm conservation programs. IID anticipates that future on-farm conservation programs will incorporate irrigation scheduling and event management either as a stand-alone measure or in combination with other conservation measures.

SOUTH SUTTER WATER DISTRICT —
A CASE STUDY OF AN AGRICULTURAL AND URBAN PARTNERSHIP

Sara F. Harper, E.I.T.[1]
Marc Van Camp, P.E.[2]

ABSTRACT

The following case study describes a partnership between an agricultural water supplier, South Sutter Water District (District), and various State Water Contractors built through the development and execution of a water transfer. In 2008, the District considered the possibility of a water transfer due to the increased costs associated with the Federal Energy Regulatory Commission relicensing process, the US Army Corps of Engineers' requirement relative to the restructuring of the Reservoir spillway to meet criteria for the Probable Maximum Flood, and other regulatory and general cost increases. In order for the District to offset a portion of these significant expenses and maintain an affordable surface water supply for its landowners, the District elected to participate in its first water transfer with the State Water Contractors. Due to the unique nature of the transfer, which included a reservoir release and an increase in groundwater use to meet local demand, this 2008 Pilot Water Transfer was considered. Ultimately, 6,909 acre-feet of water was transferred from the District to participating State Water Contractor agencies.

INTRODUCTION

Increased costs due to aging infrastructure, regulatory processes, and environmental considerations have increased the willingness for some agricultural water suppliers that have adequate water supplies to consider the possibility of water transfers. The objective of the District's participation in the 2008 Pilot Water Transfer was to offset increased costs associated with regulatory processes and District operations in order to maintain low surface water costs to District landowners in order to facilitate the conjunctive use of the groundwater basin. The historical conjunctive use within the District, lack of District-owned groundwater wells, and the limited well construction information for individual groundwater wells resulted in a pilot program approach and the classification of the transfer as a "hybrid" water transfer (reservoir release and groundwater substitution). The following case study describes the 2008 Pilot Water Transfer and the transfer process, including the coordination between the transfer participants and regulatory agencies.

[1] Assistant Engineer, MBK Engineers, 1771 Tribute Road, Suite A, Sacramento, CA 95815; harper@mbkengineers.com
[2] Principal Engineer, MBK Engineers, 1771 Tribute Road, Suite A, Sacramento, CA 95815; vancamp@mbkengineers.com

WATER DEMAND

State Water Contractor Agencies

The State Water Contractors (SWCs) are agricultural and municipal water suppliers who receive a portion of their water supply from the Sacramento River Watershed through the State Water Project (SWP) to meet their water demand. Twenty-seven of the twenty-nine SWP contractors within California are members of the SWCs. The SWCs have a process by which members elect to participate in water transfers in order to augment their SWP allocations and other supplies. Participating SWCs identify the quantity of water that is needed to be purchased through the SWCs' water transfer pool. SWCs staff identify and negotiate with sellers to procure all or a portion of the total quantity of the requested transfer water. Following the water transfer negotiations and purchase agreements, each agency is allocated a percentage of the transfer water obtained. The following table identifies the percentage of transfer water that each agency received in 2008 from the SWCs water transfer pool (E. Chapman; Principle Engineer, SWCs; oral communication; September 2009).

Table 1. State Water Contractor Pool Allocation.

State Water Contractor Agency	Percent Allocated (%)
Antelope Valley East Kern Water Agency	7.02
Dudley Ridge Water District	1.41
Kern County Water Agency	14.22
Metropolitan Water District of Southern California	68.00
Napa County Flood Control and Water Conservation District	1.87
Palmdale Water District	3.40
San Bernardino Valley Municipal Water District	3.40
Tulare Lake Basin Water Storage District	0.68
Total =	***100***

Metropolitan Water District of Southern California (Metropolitan) received the largest allocation of transfer water in 2008 and was directly involved during transfer negotiations. Metropolitan is a regional water wholesaler who supplies water to 26 member agencies and is the nation's largest provider of treated drinking water, which supplies 19 million people (Metropolitan, 2009). Metropolitan has developed a diverse water supply portfolio consisting of water from the Colorado River Aqueduct Project, SWP, local water supplies, groundwater storage projects, and transfers. Advances in technology and improved infrastructure have limited Metropolitan's dependence on imported water from the SWP and water transfers to less than half of the region's water supply portfolio. The development of additional storage reservoirs, including the recently built Diamond Valley Lake, has given Metropolitan increased flexibility to use and store imported water and local water supplies (S. Hirsch; Program Manager of Water Transfers and Exchanges, Metropolitan; oral communication; September 2009). Additional investment in conservation methods and techniques, coupled with the development of local water supplies, will maintain the balance between local and imported water supplies. Water transfers and groundwater storage programs complement Metropolitan's water portfolio, ensuring a more reliable water supply.

WATER SUPPLY

South Sutter Water District

The District was formed in 1954 to develop, store, and distribute surface water. The District owns and operates Camp Far West Reservoir (Reservoir), Camp Far West Dam, and Camp Far West Diversion Dam (Diversion Dam); located on the Bear River within Placer, Nevada, and Yuba Counties. The District's service area is located southwest of the Reservoir within Sutter and Placer Counties, south of the Bear River and east of the Feather River, and includes a gross area of approximately 66,000 acres. Figure 1 identifies the location of the District's storage facility and service area within the Sacramento Valley.

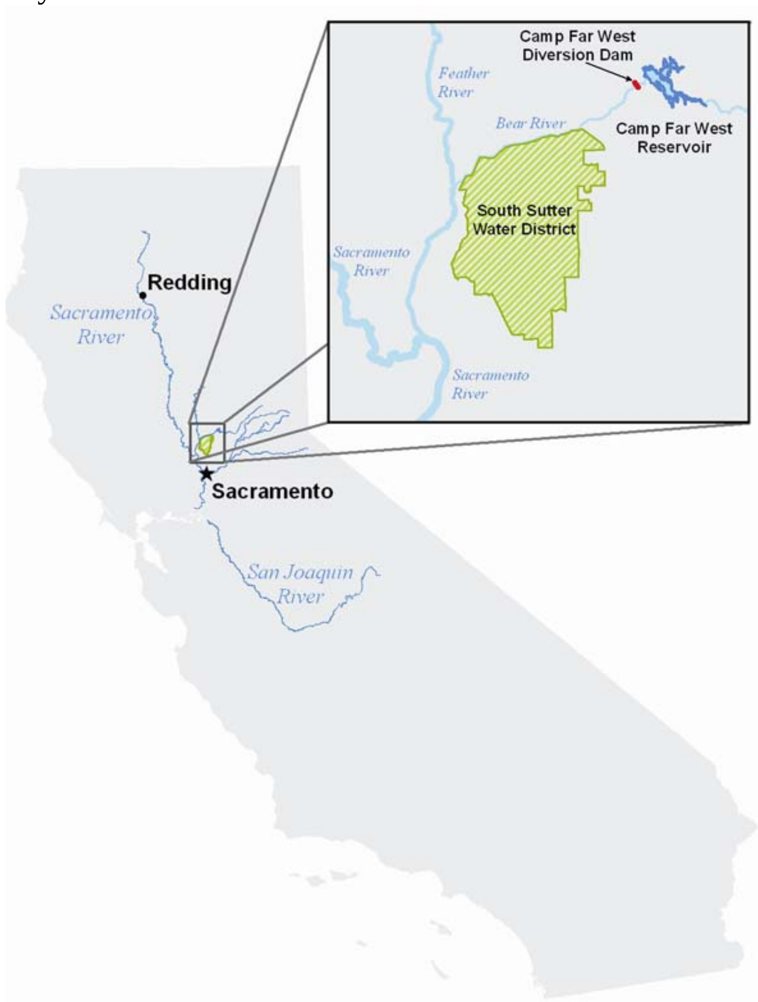


Figure 1. South Sutter Water District Location Map.

Prior to the 1960s, groundwater was the main source of water supply in most parts of the North American Sub-basin, including the District's service area. As a result, prior to the construction and subsequent enlargement of the Reservoir, groundwater levels underlying the District were steadily declining at an average rate of up to one and a half feet per year for approximately 50 years (Luhdorff and Scalmanini, 2009).

The development of the Reservoir resulted in an efficient conjunctive use project, which has operated successfully for the last 50 years. Currently, the District supplies surface water to approximately 59,000 acres within its service area. Landowners receive a supplemental surface water supply; thus reducing the amount of groundwater pumped in order to meet crop irrigation requirements. Results of monitoring documented in groundwater basin reports identify that the District is a successful conjunctive use project and indicate that the District may be well situated to participate in water transfers through greater exercise of the groundwater basin (DWR, 1997).

Groundwater

As previously identified, prior to the construction of the Reservoir, the underlying groundwater basin within the District was declining. DWR began monitoring the groundwater elevations within the basin in the late 1930s to determine the extent of overdraft occurring. Following the formation of the District and subsequent construction of the Reservoir, additional monitoring was performed at production wells to monitor groundwater levels and groundwater quality. The District’s delivery of surface water and resulting in-lieu recharge of the underlying groundwater basin successfully restored groundwater elevations to stable levels with no indication of groundwater overdraft (Luhdorff and Scalmanini, 2009).

Surface Water

As part of the development of the Reservoir, the District applied for post-1914 appropriative water rights for the storage and direct diversion of water from the Bear River. The District also holds post-1914 appropriative water rights for several small streams within the District’s service area. The water made available for the 2008 Pilot Water Transfer was petitioned under the District’s post-1914 consumptive appropriative License 11118 (Application 14804). The District’s water right License 11118 is for direct diversion of 330 cfs from May 1 through September 1, and storage of 58,370 acre-feet from October 1 through June 30 from the Bear River. Due to the quantity proposed to be transferred under the 2008 Pilot Water Transfer, it was only necessary to make temporary changes to License 11118. No changes were petitioned for the remaining water right licenses held by the District.

Conjunctive Use

As previously identified, the District owns and operates the Reservoir in order to provide a supplemental surface water supply to landowners within the District’s service area. Landowners receive approximately one-third of their irrigation season water supply needs from the District’s surface water deliveries. Prior to the irrigation season, the District allocates a surface water supply based on forecasted reservoir storage, including forecasted inflow and acreage identified by landowners seeking surface water deliveries in that given year. Landowners receive their allocation, acre-feet per acre, on a pattern dictated by crop irrigation need and conveyance canal capacity limitations.

Individual landowner groundwater pumping is used to meet the remainder of the crop irrigation requirement, which equates to approximately two-thirds of the water demand unmet by the District's surface water deliveries. The District does not own or operate any groundwater production wells. Therefore, any additional increment of groundwater is pumped by a landowner to meet crop irrigation demand regardless of the District's participation in a water transfer.

In the mid to late 2000s, record rice prices resulted in more acreage within the District's service area being planted to rice production. This factor, coupled with the recent years' dry hydrologic conditions, has resulted in a greater dependence on the groundwater basin. The quantity of groundwater pumped by individual landowners is not metered by the District; however, based on an estimate of acreage planted within the District and the cropping pattern, the District estimates that within recent years, groundwater pumping has been within the range of 150,000 acre-feet to 170,000 acre-feet.

2008 PILOT WATER TRANSFER

The District's participation in the 2008 Pilot Water Transfer was the result of the increased costs associated with regulatory processes and operations. In order to address the local issues associated with water transfers and any potential effects due to additional groundwater pumping, the District held a public meeting to inform individual landowners and receive input relative to the water transfer. At this public meeting, comments from landowners were addressed, including increased pumping costs and the potential for increased costs for surface water deliveries. It was estimated that the potential reduction in surface water deliveries was equivalent to approximately 0.1 acre-feet per acre and would be offset by an increase in the quantity of groundwater pumped by each individual landowner. This relatively small increase in pumping head and associated costs, as compared to the relatively large increase in surface water delivery rates proposed to be charged to landowners if the District did not participate in the water transfer, resulted in landowner approval and the unanimous approval by the Board of Directors to participate in the 2008 Pilot Water Transfer. The following section identifies the regulatory approvals necessary to affect the 2008 Pilot Water Transfer.

Regulatory Approval

In order to execute a temporary water transfer within California based on post–1914 appropriative water rights, a water right holder is required to petition and obtain the approval of the State Water Resources Control Board, Division of Water Rights (Division). As part of the Petition process, a water right holder also has to provide public notice and respond to protests relative to a proposed water transfer. In addition, the water right holder is required to coordinate with the Department of Fish and Game (DFG) and the appropriate Regional Water Quality Control Board (RWQCB) to ensure that the proposed transfer does not unreasonably affect fish and wildlife or injure other downstream water right holders. For water transfers that utilize SWP facilities, the approval and execution of a Storage and Conveyance Agreement with the Department of Water Resources is also necessary.

<u>State Water Resources Control Board.</u> Pursuant to California water right law, an individual water right holder can petition the Division to temporarily change the point of diversion, point of rediversion, place of use, or purposes of use in order to temporarily transfer water given the following conditions:

1. Transferrable quantity is limited to the amount of water that would have been consumptively used or stored in absence of the transfer,
2. The proposed transfer does not injure any legal user of the water, and
3. The proposed transfer would not unreasonably affect fish, wildlife, or other instream beneficial uses. (Thomson and Reuters/West, 2009)

The District filed a Petition for Temporary Change to change the point of rediversion, place of use, and purpose of use under License 11118 to transfer up to 10,000 acre-feet of stored water from the Reservoir to the aforementioned SWCs. Following the Division's review of the Petition, including publication and appropriate public comment period as identified in California Water Code §1726, the Division approved the temporary water transfer by issuing a water right Order. No protests were received relative to the District's Petition for Temporary Change. The water right Order authorized the transfer of up to 10,000 acre-feet of water, at a rate not to exceed approximately 120 cfs, from the Reservoir to participating SWCs.

<u>Department of Fish and Game.</u> DFG received a copy of the District's petition package at the time it was filed with the Division. The package included information relative to the assessment of the potential effects of the proposed water transfer. In addition, District staff discussed the proposed water transfer with DFG in order to assess the potential effects of the increased releases from the Reservoir relative to fish and wildlife. Of particular importance, was the concern of potentially attracting anadromous fish into the Bear River, due to increased flow rates. Due to the relatively warm temperatures present within the Bear River during the period of the proposed water transfer, it has been referred to as a hostile environment for anadromous fish species. Through a comparative analysis of projected flows within the Bear River and the Feather River, it was determined that the increase in Bear River flows as a result of the transfer would be less than 5% percent of the anticipated Feather River flows. As a result, a biologist determined that this relatively small increase in flows would not attract anadromous fish into the Bear River. In addition, due to the timing of the water transfer, July through September, the primary fish species of concern would not be present within the Feather River. Therefore, it was determined that the transfer would have a less than significant effect on fish species.

<u>Regional Water Quality Control Board.</u> District staff advised the Central Valley RWQCB of the proposed water transfer to identify and address potential effects to water quality within the Bear River or the Feather River. Based on these discussions, the increase in flows within the Bear River was believed to improve water quality within the Bear River, and potentially the Feather River. The main area of concern raised by the Central Valley RWQCB was relative to tailwater effects to water quality. No change in cropping pattern was proposed by the District or its landowners. District staff identified

that the District and its landowners operate to minimize the quantity of tailwater leaving the District's service area. Following these discussions, it was determined there would be no change in operations and no detrimental effect on water quality within the Bear River and Feather River.

Department of Water Resources. In order for the transfer water to be conveyed through SWP facilities, each buyer and the District entered into Storage and Conveyance Agreements with DWR. The 2008 Pilot Water Transfer proposed to release water from the Reservoir for delivery to the SWCs at the Diversion Dam. Water made available pursuant to the 2008 Pilot Water Transfer, that otherwise would have been delivered to landowners, would need to be made up with groundwater pumping by individual landowners. As part of the Storage and Conveyance Agreement negotiation process for the 2008 Pilot Water Transfer, and as further described below, the District and DWR worked cooperatively to modify the existing groundwater monitoring well network to spatially distribute monitoring wells within the District. DWR and the District developed a Groundwater and Surface Water Monitoring Program and a Third-Party Impacts Action Plan, as required pursuant to the Storage and Conveyance Agreement. The District, DWR, and the SWCs executed individual Storage and Conveyance Agreements for the 2008 Pilot Water Transfer on August 15, 2008.

Classification of the 2008 Pilot Water Transfer

A primary complication to the negotiation process of the 2008 Pilot Water Transfer was the transfer's definition. The proposed transfer did not follow the general guidelines identified for either a groundwater substitution or reservoir release type transfer. The following section defines the two types of transfers and the considerations involved in classifying the 2008 Pilot Water Transfer as a combination of the two.

Groundwater substitution transfers involve the water transfer participant pumping groundwater to meet crop irrigation requirements in lieu of diverting surface water. Specific guidelines for groundwater substitution transfers are followed, including criteria to determine the eligibility of groundwater wells for participation in this type of transfer. Specific restriction for wells within one mile and two miles of a river are applied based on a review of the groundwater well completion record. Typically, wells within a participating entity are designated to participate in a groundwater substitution transfer; and the quantity transferred is measured at each groundwater well. The quantity of groundwater considered as transferred is the quantity pumped, less a pre-determined historical base quantity, if applicable.

Reservoir release type transfers involve the release of water from storage. The volume of water is normally measured at a point downstream of the reservoir where other required releases are measured, such as the instream flow requirements. The volume of stored water considered as transferred is the volume above a historical baseline, which includes the minimum release requirements.

The District's 2008 Pilot Water Transfer proposed to release water from the Reservoir; and thence, the Diversion Dam where it would be measured. This resulted in a reduced surface water allocation to landowners; and therefore, the quantity of water that otherwise would have been delivered to landowners was to be made up by individual landowner groundwater pumping. Approximately 150 groundwater production wells have been historically monitored by DWR, the majority of which were installed in the 1920s-1930s. The total number of groundwater production wells within the District's service area are unknown; however, District staff approximates that there may be as many as 400 groundwater production wells within the District's service area. Due to the time period of construction of these wells, well construction information is not available for a large percentage of groundwater production wells. The lack of information regarding the location and construction of groundwater wells within the District resulted in a pilot transfer approach and classification of the 2008 Pilot Water Transfer as a hybrid type transfer.

Available Water for the 2008 Pilot Water Transfer

Through the negotiation process for the 2008 Pilot Water Transfer, DWR expressed concern as to whether the full amount of water proposed to be released from the District's Reservoir would be physically available for delivery to the SWCs through SWP facilities. In groundwater substitution transfers, a complication in the determination of the water made available is the hydrologic connectivity of water sources. The principle concern is that water pumped and made available for transfer induces recharge from hydrologically connected surface water stream sources, shifting the water physically made available from one source to another instead of providing additional water supplies to the proposed buyer. This has the potential to affect the water that would have been available to the other SWP and Central Valley Project (CVP) absent the water transfer.

Prior to 2008, DWR credited groundwater substitution transfers on a one-to-one basis, meaning that the amount of water pumped was equivalent to the amount of water to be transferred. During the 2008 negotiations, DWR identified that groundwater substitution transfers would no longer be credited on a one-to-one basis. Research, analysis, and data relative to the surface and groundwater interaction were, and continue to be, limited. In order to affect groundwater substitution type transfers in 2008, an assumed depletion loss was proposed to address this concern relative to the potential effects to the SWP and CVP.

The absence of flow measurement devices at groundwater pumps within the District, and the limited access to well completion and historic pumping records, further complicated the negotiation process and determination of the potential effects to the groundwater basin. Therefore, additional research and negotiations were conducted in assigning a depletion loss value to the 2008 Pilot Water Transfer. A historic analysis of monitoring wells located within the District indicates that in almost every year, the groundwater basin is recharged during the subsequent winter period. Both parties agreed that the precise depletion loss value was not known; however based on modeling conducted for the Sacramento Valley Regional Water Management Plan and an analysis of historic groundwater response to water demand within the District, a 6% depletion loss was agreed to. The depletion loss was shared equally between the buyers (3%) and seller (3%).

2008 Pilot Water Transfer Surface Water Releases

The District released water from the Reservoir, thence its Diversion Dam through dedicated water transfer weirs. The water elevation at the Diversion Dam pool was measured by a continuous water level recorder. The District fabricated and installed weir plates in order to calculate the amount of water released based on a standard weir equation. The Diversion Dam configuration during the 2008 Pilot Water Transfer is shown in Figure 2.

Figure 2. 2008 Pilot Water Transfer Weir Configuration.

Groundwater and Surface Water Monitoring and Mitigation Plan

Due to the increased groundwater pumping by individual landowners within the District, and the potential for third-party impacts, the District and DWR reviewed and updated the groundwater level monitoring network within the District's service area and established a Groundwater and Surface Water Monitoring and Mitigation Plan. Groundwater elevation and groundwater quality field parameters, including specific conductance, pH, and temperature, were collected from groundwater production wells identified within the monitoring well network. DWR also monitors additional wells within and near the District's service area for other purposes on a semi-annual and monthly basis. Overall, data from 85 wells relating to groundwater elevations and groundwater quality were collected and analyzed.

Streamflow was measured at four locations, including the Camp Far West Diversion Dam (CFW DD), USGS (Gage 11423800) – Bear River Fish Release below Camp Far West Reservoir, USGS (Gage 11424000) – Bear River near Wheatland, and the DWR – Gage (BPG) Bear River at Pleasant Grove Road in order to verify the surface water releases from the Diversion Dam.

2008 Pilot Water Transfer Results

The 2008 Pilot Water Transfer volume was initially estimated at 10,000 acre feet. Due to dry hydrologic conditions and the uncertainty relative to the forecasted inflow to the

Reservoir, ultimately, 6,909 AF (7,123 AF total released minus a 3% depletion loss of 214 AF) was transferred. Table 2 identifies the quantity delivered pursuant to the transfer to each participating SWC.

Table 2. Quantity delivered pursuant to the 2008 Pilot Water Transfer to each participating State Water Contractor.

State Water Contractor	**Percent Allocated (%)**	**Approximate Quantity Delivered [3] (Acre-feet)**
Antelope Valley East Kern Water Agency	7.02	485
Dudley Ridge Water District	1.41	97
Kern County Water Agency	14.22	983
Metropolitan Water District of Southern California	68.0	4,698
Napa County Flood Control and Water Conservation District	1.87	129
Palmdale Water District	3.40	235
San Bernardino Valley Municipal Water District	3.40	235
Tulare Lake Basin Water Storage District	0.68	47
	Total Quantity Delivered	***6,909***

Following the 2008 Pilot Water Transfer, DWR, and the District worked cooperatively to draft the South Sutter Water District 2008 Pilot Water Transfer Groundwater and Surface Water Monitoring Summary (Joint Report) summarizing the monitoring performed during the 2008 Pilot Water Transfer and any potential effects attributable to the water transfer. The reduction in surface water deliveries to the District's landowners as a result of the 2008 Pilot Water Transfer corresponds to an approximate 4% increase in the total estimated groundwater pumped within the District's service area during the 2008 irrigation season (DWR and South Sutter Water District, 2010).

As previously identified, groundwater data from 85 wells within and near the District were collected and analyzed. Figure 3 identifies the location of groundwater wells monitored within and near the District. The wells are identified by monitoring agency and include groundwater levels and groundwater quality data collected during the 2008 Pilot Water Transfer period within the monitoring network for the 2008 Pilot Water Transfer and additional data collected from groundwater wells within and near the District.

[3] Approximate quantity delivered pursuant to the transfer is at the point of delivery, Camp Far West Diversion Dam; and therefore, does not include the SWCs assumed portion of the depletion loss (3%) or transportation losses from the point of delivery to the SWCs diversion facilities.

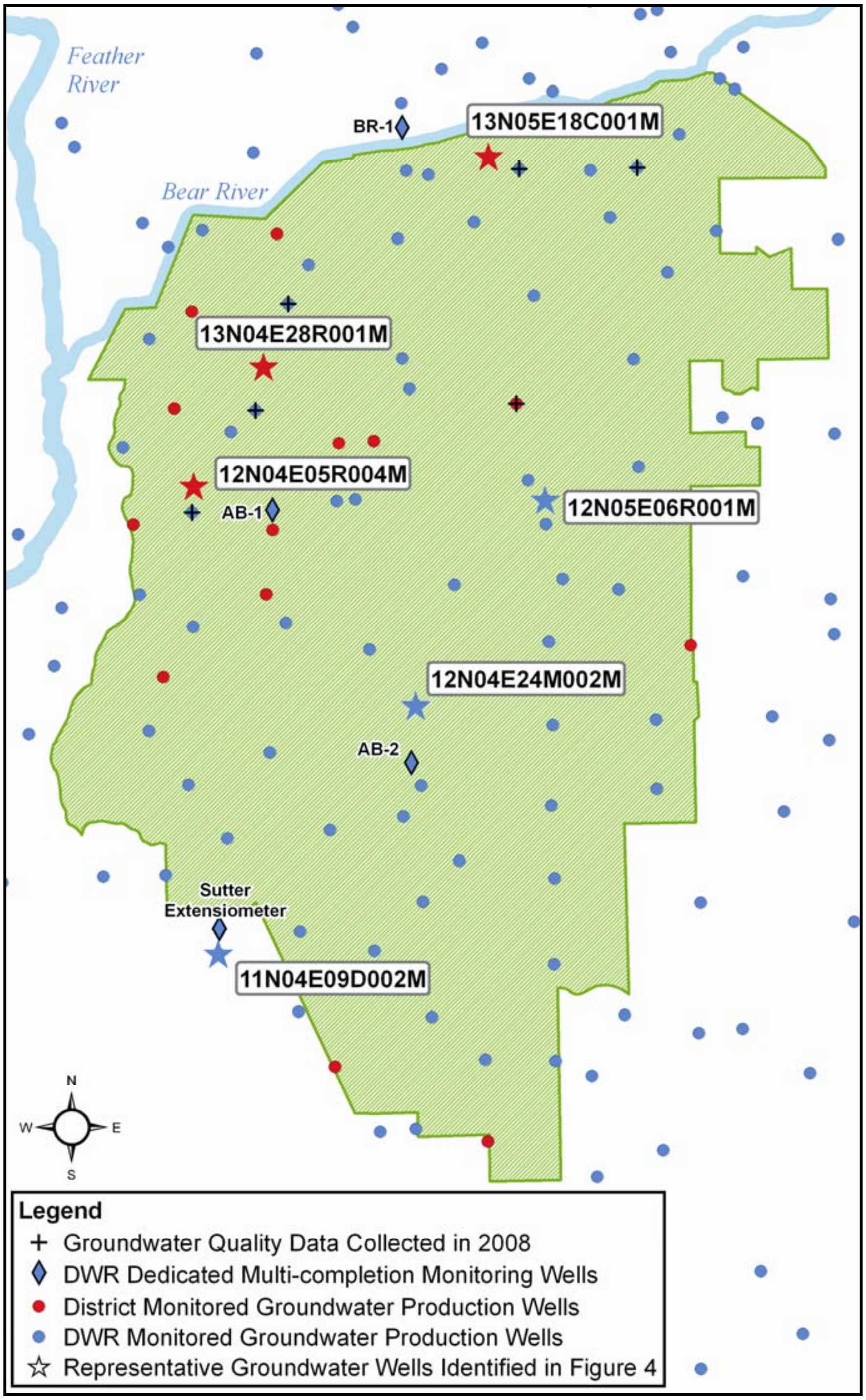


Figure 3. Location of Groundwater Monitoring Wells within South Sutter Water District.

Figure 3 identifies that the majority of the monitoring wells within the District are also production wells. Four multi-completion dedicated groundwater monitoring wells, including an extensiometer, are also located within and near the District, BR-1, AB-1, AB-2, and the Sutter Extensiometer. Groundwater quality data was recorded at four groundwater production wells during the transfer period.

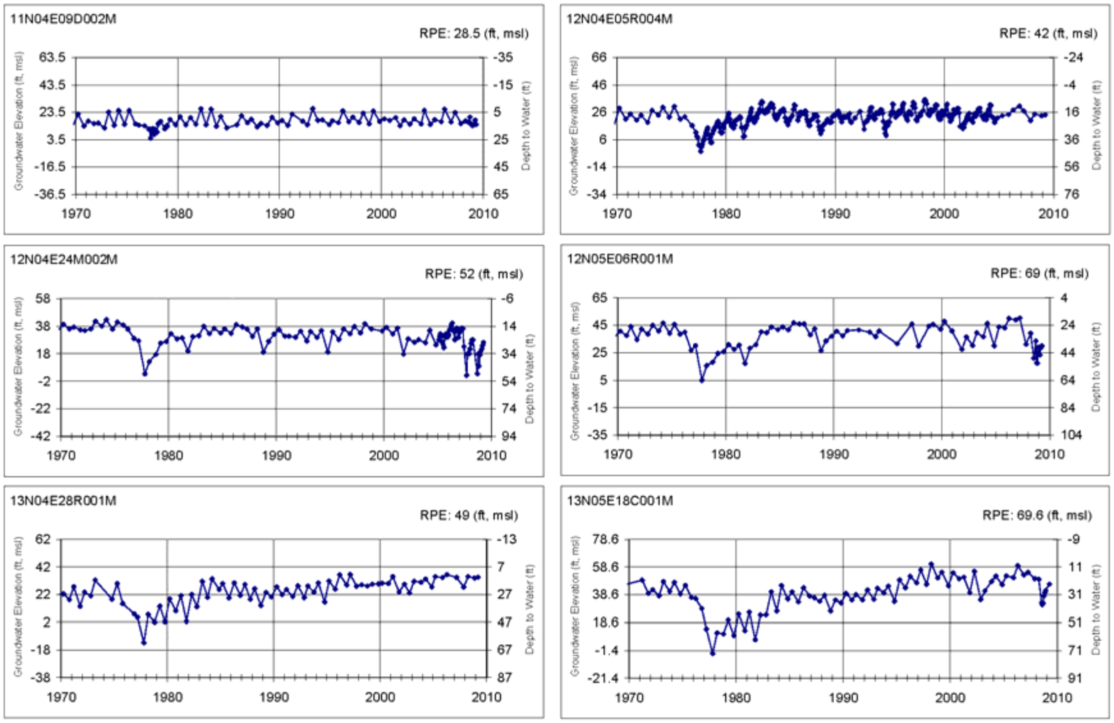


Figure 4. Representative Groundwater Hydrographs within and near South Sutter Water District.

Figure 4 identifies the groundwater hydrographs of representative wells identified in Figure 3 for the period of 1970-2008. As identified in the groundwater hydrographs, the basin historically has responded to dry hydrologic periods with declines to the groundwater basin. The 1977-1979 drought is identified by declines and subsequent recoveries to groundwater elevations. As shown in Figure 4, groundwater elevations during the period of the 2008 Pilot Water Transfer are within historical groundwater levels observed. The dry hydrologic conditions, coupled with the increased acreage planted to rice production, resulted in an increased dependence on the groundwater basin. It was difficult, given the relatively small increase in groundwater pumping, to differentiate between the potential effects due to the 2008 Pilot Water Transfer from other factors. However, the results of the draft Joint Report indicate that overall, groundwater conditions underlying the District in 2008 remained consistent with historical observations and the basin did not experience abrupt changes, which may have been attributable to the 2008 Pilot Water Transfer (DWR and South Sutter Water District, 2010). All groundwater monitoring wells within the District recovered to pre-transfer (April, 2008) groundwater elevations by March, 2009. No third party impacts as a result of the 2008 Pilot Water Transfer were identified.

Surface water monitoring performed during the 2008 Pilot Water Transfer downstream of the point of delivery further verified the quantity of water released from the Reservoir and Diversion Dam. Figure 5 identifies the location of the gage stations.

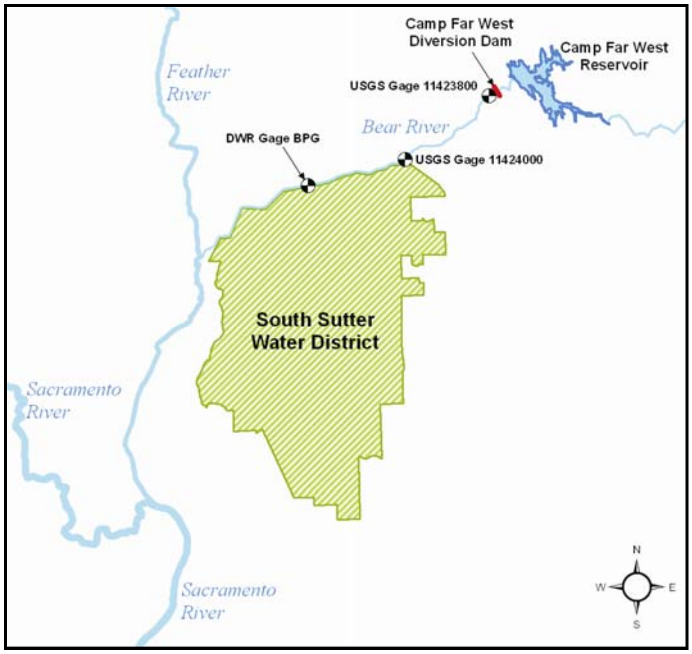


Figure 5. Bear River Gage Stations.

The first USGS Gage downstream of the Diversion Dam, USGS Gage 11423800, measures the dedicated fish release by the District for instream flow obligations. This quantity, in addition to the quantity released over the Diversion Dam pursuant to the 2008 Pilot Water Transfer and the District's other existing agreement, (Bay-Delta Settlement Agreement, BDSA) represents the total quantity of water released into the Bear River by the District. Figure 6 identifies the rate of release from the District's Diversion Dam and the flow rates at USGS Gage 11424000 and DWR Gage BPG.

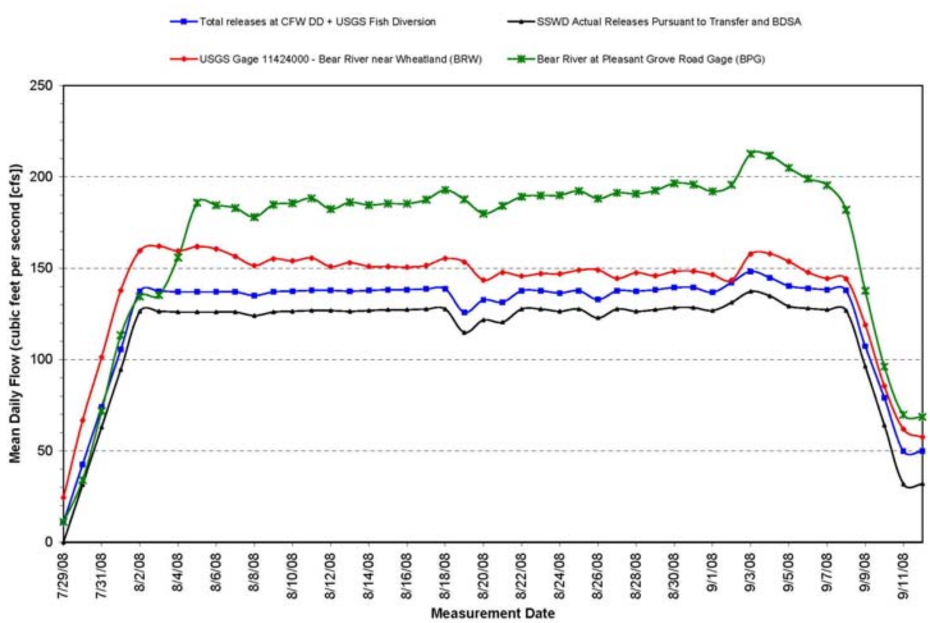


Figure 6. Surface Water Monitoring Performed Pursuant to the 2008 Pilot Water Transfer (Source: DWR and South Sutter Water District, 2010).

As identified in Figure 6, the total releases at the Diversion Dam, plus the fish release, are accounted for at both downstream gages. The daily variations in releases are a result of operational issues and considerations that are common to systems of this nature.

Protection of the Groundwater Resource

Following the 2008 Pilot Water Transfer, the District updated its Groundwater Management Plan (GWMP). The protection of the underlying groundwater basin, and the assurance of a stable groundwater and surface water supply for District landowners, is a principal concern of the District. The update to the GWMP analyzes historic trends within the region and identifies the District's Best Management Objectives (BMOs) for protection of the resource and the potential development of alternative water supplies for consideration in future water transfers.

BUILDING PARTNERSHIPS FOR FUTURE WATER TRANSFERS

Water transfers require a significant amount of coordinated planning and operations between a number of parties, including the buyer, seller, and regulatory agencies. The use of storage and conveyance facilities belonging to or operated by entities not directly involved in the buying or selling of water further complicates the accounting and negotiation process. Therefore, the need for the development of a transparent and positive relationship between buyers, sellers, and regulatory agencies is essential to the success of executing a water transfer.

Following the 2008 Pilot Water Transfer and the development of a positive working relationship between the regulatory agencies and the District, the District negotiated and executed a contract for a 2009 water transfer to DWR's 2009 Drought Water Bank, of which Metropolitan is the largest participant. The foundations built during the 2008 water transfer facilitated and expedited the 2009 water transfer negotiations and resulted in 10,000 acre-feet of water being transferred to agriculture and municipal water purveyors with critical water supply needs. The District continues to monitor the underlying groundwater basin to develop a better understanding of the groundwater basin response to withdrawals and in order to protect this valuable resource. The District will continue to review the opportunity for future water transfers to fulfill the financial obligation associated with infrastructure improvements, regulatory compliance, and overall operation costs.

CONCLUSIONS

The multiple forms of water transfers and their flexibility make water transfers a promising water management tool. The benefits resulting from a water transfer can serve a multitude of purposes, including agriculture water supplies, municipal water supplies, and environmental beneficial uses. In addition, these partnerships provide economic benefits for funding infrastructure improvements. The flexibility associated with water transfers during drier hydrologic conditions, results in the movement of water supplies to meet the demand of a region whose local water supplies and reserves are limited for numerous reasons. In this case study, the District and the SWCs, specifically Metropolitan, worked cooperatively to build the transparent and positive working relationship to successfully effect the 2008 Pilot Water Transfer. The complexities involved with water transfers due to legal, third party, and complex technical issues require strong partnerships to address and overcome the multitude of considerations for the success of future water transfers.

REFERENCES

Department of Water Resources, South Sutter Water District. *Summary of South Sutter Water District 2008 Pilot Water Transfer Groundwater and Surface Water Monitoring Summary*. Sacramento, CA: 2010:1-16.

Department of Water Resources – Central District. *Feasibility Report - American Basin Conjunctive Use Project*. Memorandum Report. Sacramento, CA: DWR Reprographics; 1997: 11-107.

Department of Water Resources. *Groundwater Level Data for Well No. 12N05E6R001M*. http://www.water.ca.gov/waterdatalibrary/groundwater/hydrographs/report_html.cfm?WellNumber=12N05E6R001M. Updated December 2009. Accessed January 13, 2010.

Luhdorff and Scalmanini. *South Sutter Water District Groundwater Management Plan*. Updated 2009. Sacramento, CA: 2009: 10-13.

Metropolitan Water District of Southern California. *Conservation and More at a Glance.* http://www.mwdh2o.com/mwdh2o/pages/news/at_a_glance/Conservation.pdf . Updated May, 2008. Accessed September 10, 2009.

Metropolitan Water District of Southern California. *Profile – A summary of Delivery and Distribution, Facilities and Equipment.* http://www.mwdh2o.com/mwdh2o/pages/news/at_a_glance/mwd_profile.pdf . Updated October 2008. Accessed September 10, 2009.

Thomson Reuters/West. *California Water Code*. Sacramento, CA: 2009: 84-86.

MANAGING THE EASTERN SAN JOAQUIN COUNTY SUB-BASIN
AN URBAN/AG PARTNERSHIP CASE STUDY
STOCKTON EAST WATER DISTRICT

Kevin M. Kaufman, P.E.[1]

ABSTRACT

Senior agency managers work with the 'politics' of the water industry almost everyday while doing their job of serving the governing board elected or appointed to set policy for their water agency. Conflict in general arises from the 'bottom-line' issues like the cost of services charged by these agencies. From an individual's perspective, cost can become a very personal issue. From a company or entity's perspective, cost can become a significant challenge to their budgeting process. When a water agency is perceived as taking an approach with an individual, group, company, or entity that is prejudicial or inequitable, the governing board member's telephones ring too often. Working with the customers of this agricultural/urban water district to spend money on infrastructure intended to assure a sustainable and reliable water supply has raised some interesting communication and policy challenges. For ten-years, the Stockton East Water District (SEWD) has applied various approaches to achieve its objectives in reaching this water supply goal. Although these objectives have not yet been achieved, it was felt to be interesting for SEWD to share what it has learned, and where it might head in the future as a result of the progress made to date.

INTRODUCTION

SEWD is a water conservation district authorized by the Legislature to secure supplemental surface water sources in order to provide a sustainable water supply for agricultural and urban users, and residents that rely on the San Joaquin County Sub-Basin of the San Joaquin Valley Groundwater Basin (Basin).

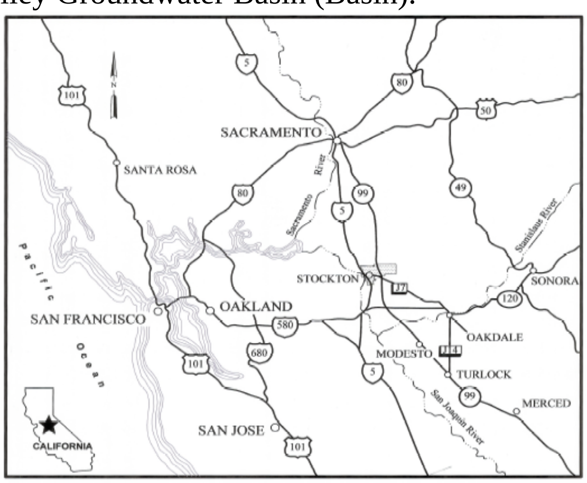


Figure 1. Location map

[1] General Manager, Stockton East Water District, P.O. Box 5157, Stockton, CA. 95205; kkaufman@sewd.net

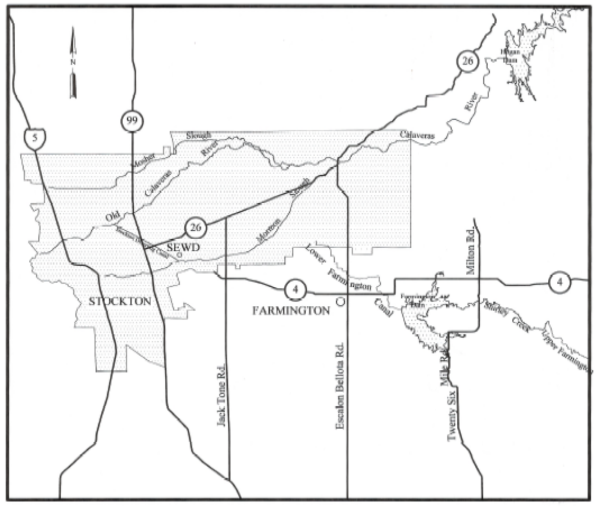


Figure 2. Vicinity Map

CHALLENGED BASIN & UNDERSTANDING TODAY

The Basin has been subject to long-term and continued overdraft and saline intrusion from its western boundary under the Sacramento-San Joaquin River Delta. The total cumulative Basin overdraft to date is estimated to be between 2.5 and 3.0 million AF. Saline waters have contaminated groundwater under the urban area, moving generally from the west to the east, contaminating the City of Stockton's groundwater supply. The leading edge of this intrusion approaches State Highway 99 in the southern half of the City of Stockton (see illustration).

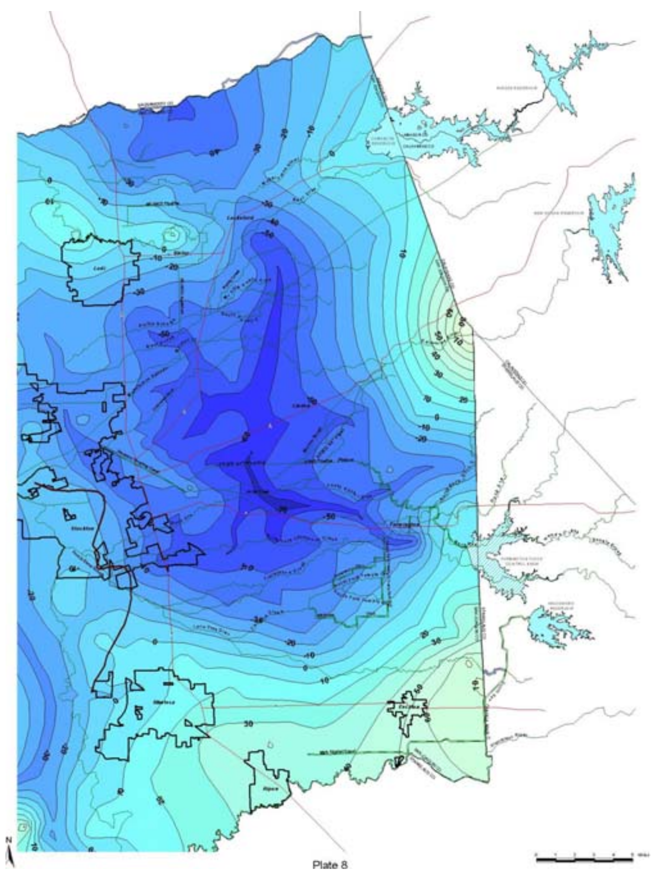


Figure 3. Depth to Groundwater Relative to MSL

Overdraft of the Basin results from agriculture and urban groundwater pumping that exceeded its ability to naturally recharge over the past 60 years.

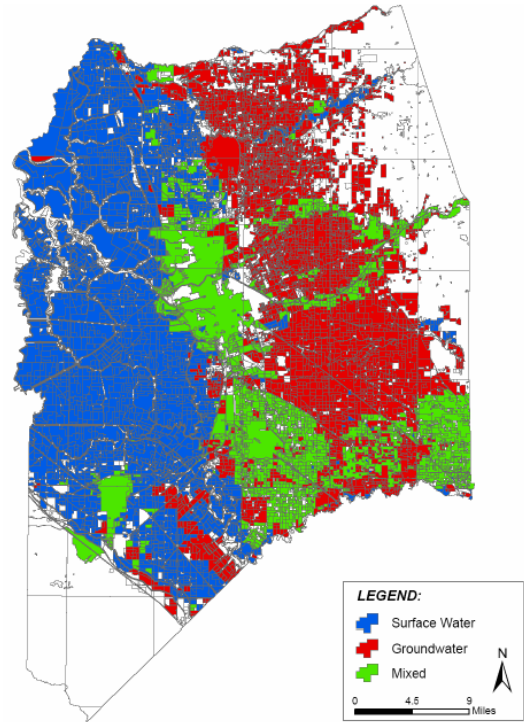


Figure 4. Groundwater and Surface Water use in San Joaquin County

If one looks at the annual average hydrology of surface water availability data (see below), one might conclude that adequate surface water exists to meet local water demands. However, the hydrologic variability from year to year makes reliance on only a surface water supply unreliable, and historically has led this region to rely on groundwater pumping as the primary supply. Had the region secured adequate water rights and constructed surface water storage reservoirs early on, there would have been less reliance on and damage caused from excessive groundwater pumping.

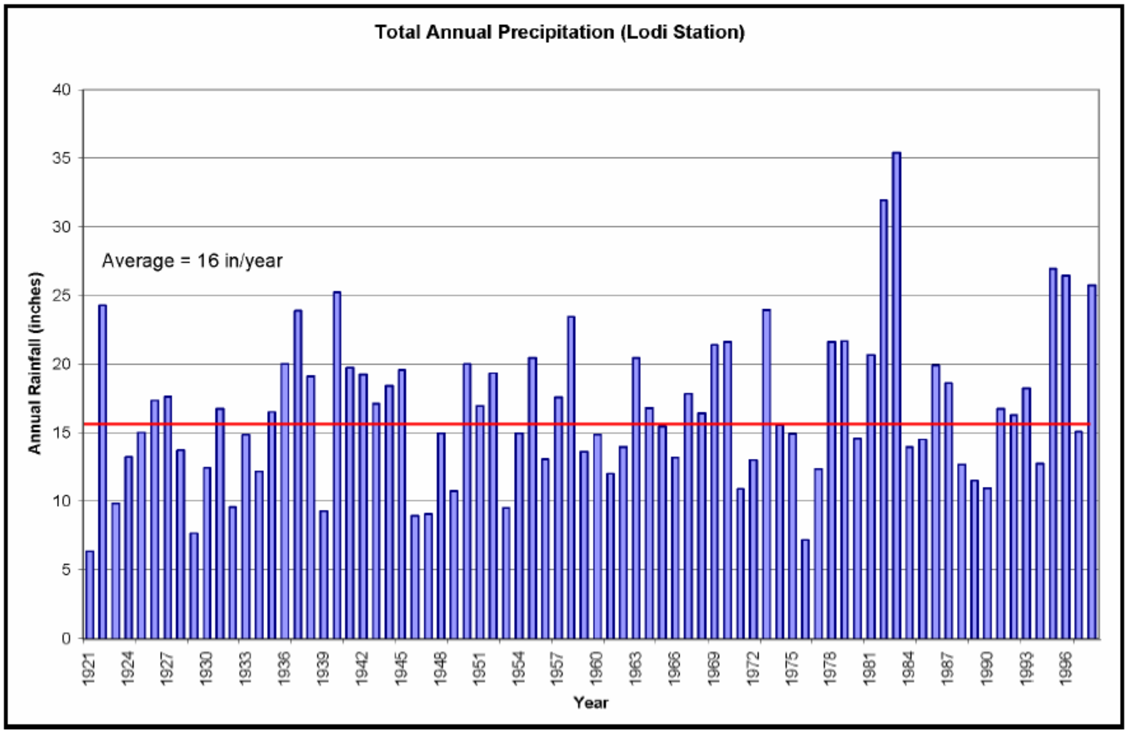


Figure 5. Annual Precipitation (Lodi Station)

To meet water demand projections, SEWD is developing infrastructure to promote the use of a conjunctively managed surface and groundwater supply. A portion of the vacated Basin resulting from overdraft can be used to 'bank' surface water in the ground for times when adequate surface water supplies are not available. The portion not pumped in dry years allows groundwater levels throughout the Basin to recover.

Artificial groundwater recharge assists natural recharge by diverting surface water and placing it into the Basin for the purposes of raising groundwater levels and storage for later withdrawal. Groundwater recharge and banking can be achieved either through the use of surface water 'in-lieu' of pumping groundwater (passive recharge), or by directly recharging the Basin by flooding fields or constructed percolation ponds (active recharge). The estimated storage capacity of the Basin for banking is estimated to be in excess of 1.5 MAF. Surface water can be 'directly' recharged and stored in the ground whenever surface water supplies exceed demands. 'Passive' recharge and storage is more seasonally dependent. It is accomplished by utilizing available surface water to meet irrigation and municipal demands, and leaving local groundwater or stored surface water in the ground in the event of a dry period when it will be needed.

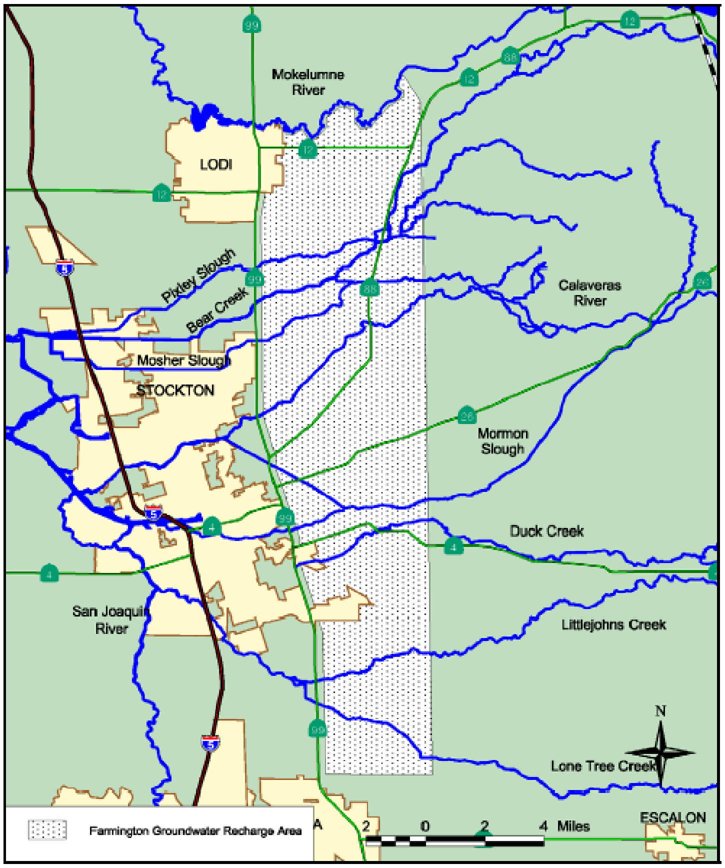


Figure 6. Farmington Groundwater Recharge Area

The City of Stockton urban area, recognized the need to use surface water 'in-lieu' of continuing to pump groundwater, and financed the construction of a 30 MGD drinking water treatment plant (DWTP), which began operations in 1977. This DWTP has a current California Department of Public Health rated capacity of 50 MGD. When surface water supplies are available, the DWTP operates in excess of this capacity, meeting about 70% of the annual demand of the urban area. A new DWTP is being constructed by the City of Stockton so that in most years 100% of the urban demand will be met with surface water supplies. In years when surface water supplies cannot meet the urban demand, surface water stored in the ground by this in-lieu method will be pumped to meet the urban demand.

Figure 7. 2007 aerial photo of DWTP looking east

Due to the operation of the SEWD DWTP, groundwater levels under the urban area have generally been more stable or have risen. A benefit of rising groundwater levels under the urban area in addition to the banking component is that the progress of saline intrusion may be thwarted by a mounding effect of this urban in-lieu recharge effort.

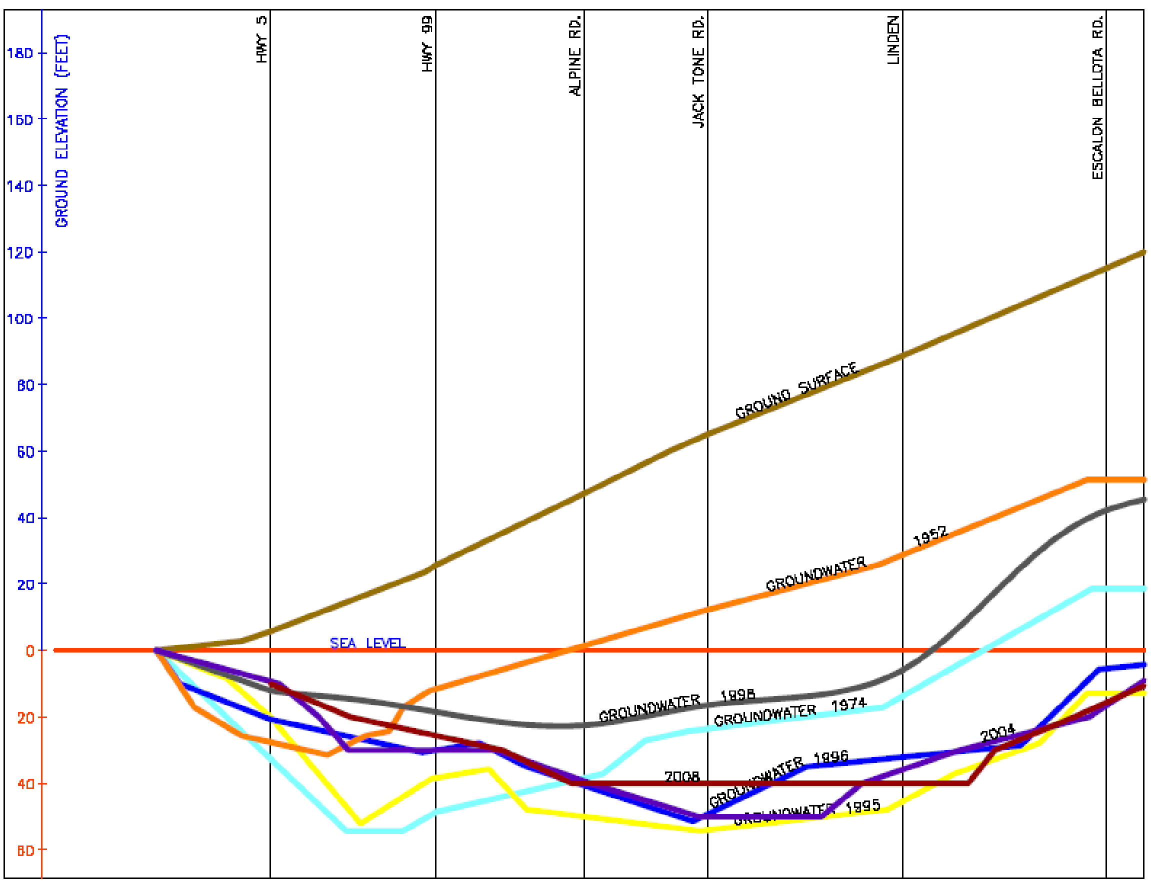


Figure 8. Groundwater Level along Hwy 26

With the saline intrusion coming from under the Delta to the west, this hydraulic barrier/mound may impede its progress toward the low-point of the Basin to the east.

The agricultural area of SEWD, to the east of the urban area, has experienced greater overdraft than the urban area, and is over the low-point of the Basin (80 feet below sea level). Since before the 1930's, agricultural interests recognized the benefit of using surface water to recharge the Basin. The Linden Irrigation District, predecessor to the SEWD, built flashboard dams in the Calaveras River, allowing surface water to percolate within the natural river channel for the benefit of the Basin. This practice continues today along with added surface water diversions from the river so agriculture can use surface water in-lieu of pumping groundwater.

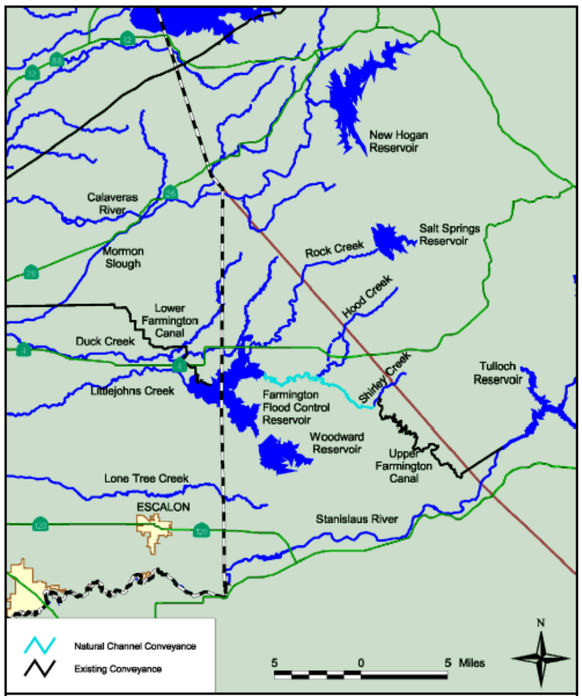


Figure 9. New Melones Conveyance

In order to obtain a sustainable water supply for the urban area, the agricultural area of SEWD must be developed with infrastructure to deliver surface water in-lieu of groundwater pumping. Less than 20% of the 55,000 acres of irrigated agriculture within SEWD currently use surface water. This percentage is not surprising given the fact that the number of acres adjacent to the canals and natural streams currently using these water ways to distribute surface water is small. If expanded infrastructure is constructed to deliver surface water to more acreage, the proper management of surface and groundwater in the agricultural portion of the SEWD is achievable. The storage and banking of water under the agricultural area of SEWD is expected to be the ultimate saving-grace for the urban area in dry years since this is the largest portion of the overdrafted Basin. Solutions can be found through water resources planning and engineering; right? [If the solution were this easy to come by, everyone would want the job!]

COMMUNICATION & CUSTOMER CLASS CHALLENGES

The history of securing and managing water supplies in California varies depending on local and regional geography and attitudes.

For example, in contrast to SEWD, the City of Modesto (located 30 miles SE of Stockton) claims they are rich in water; and they are because of their location south of the Stanislaus River and astride of the Tuolumne River, and their foresight to develop and protect these surface water resources. Many other irrigation districts were equally fortunate both in geography and foresight, and today have ample surface water supplies. The Eastern San Joaquin County region, where SEWD hails, has not been as fortunate.

The Eastern San Joaquin County region's misfortune can be explained by three primary factors: its lack of ideal geography for diverting surface water; its lack of foresight for water management planning; and its unenviable luck in trying to secure and protect what might have been.

Located between the Mokelumne and Stanislaus River watersheds, SEWD has limited surface water supplies from the existing rain-fed streams. The Linden Irrigation District and the City of Stockton acquired water rights on the Calaveras River, which are considered as good as gold today. While the Mokelumne River runs through the City of Lodi and the North San Joaquin WCD, they were forced to settle for a trickle of the river's water thanks to a 1948 decision by the State Engineer granting rights to the river to the East Bay Municipal Utility District. There is potential that a more equitable court may award these local agencies a fairer share of the Mokelumne River supply in the future.

Three 78-inch diameter pipelines transmit Mokelumne River water from above Pardee Dam to EBMUD's service area. These pipelines bisect the City of Stockton. Reportedly, during their construction, a neighborly EBMUD offered the City a tap or two off of these pipelines in the event the City of Stockton would ever want to buy some of this water from EBMUD. The City fathers at the time saw no value in the offer, saying that they had enough groundwater for their foreseeable future. This failure to invest in the future of course is considered the mistake of the century. In the City's defense, however, the city water system was a private water company at the time, with their interests possibly focused only on the short-term. The City became much more active in water issues later in the 20th century, and today has its own water system that has a water demand equivalent to that of the older private water company.

Although the City of Stockton did secure a water right on the Calaveras River, at the time it was more interested in flood protection than water supply. Following the flood of 1955, the New Hogan Dam was designed and constructed by the US Army Corps of Engineers, and completed in 1964. At that time, the City's water right was absorbed or gifted by the water right secured by the USBR, and contracted to the SEWD and its foothills neighbor, the Calaveras County Water District.

On the agricultural side of SEWD, even more significant lack of foresight occurred. Although the Linden area of the district had a great water right and was able to provide surface water to properties adjacent to the Calaveras River, the rest of the district had few surface water options. Despite this, using water from the Calaveras River until the 1977-78 droughts, SEWD delivered over 30,000 AFA of surface water to properties adjacent to the Calaveras River system. Forced to install deeper agricultural wells during the drought, many users never went back to using surface water. To this day, SEWD has yet to provide as much surface water to its agricultural customers. The 1988-92 droughts had similar reductions in surface water use. SEWD offers incentives for the growers to use surface water in-lieu of pumping groundwater, and agricultural demand has now grown to nearly the 30,000 AFA milestone.

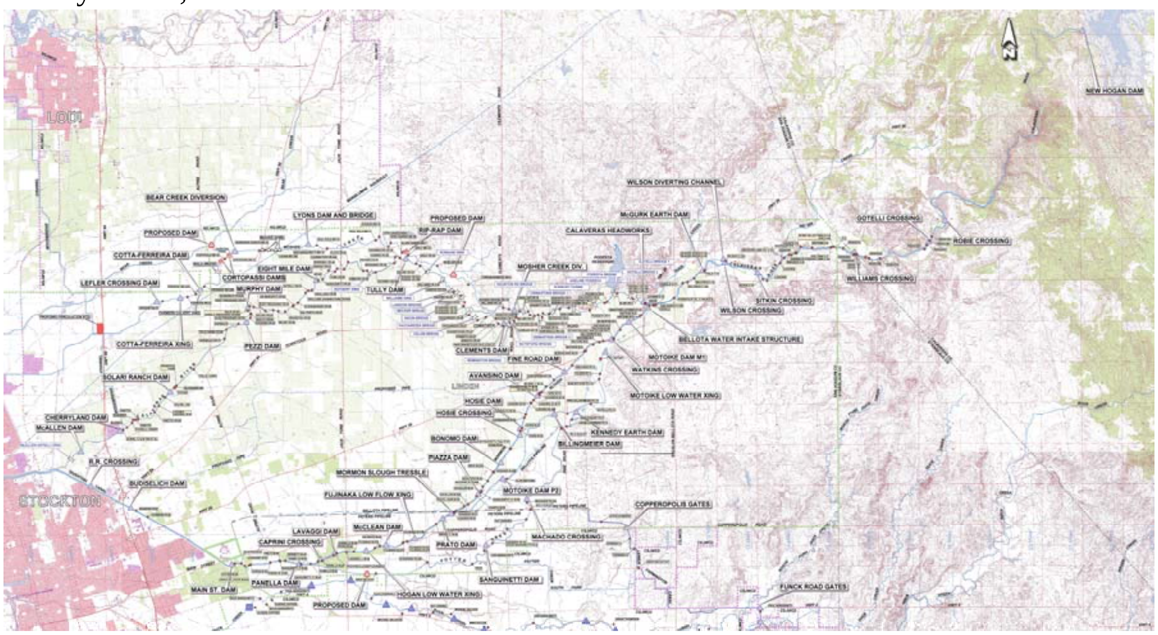


Figure 10. SEWD Agricultural Map

Due to the perceived unreliability of the surface water, and the expense of maintaining a dual surface and groundwater system, the agricultural community has not been willing to invest in the infrastructure needed to make surface water more accessible. In the 1979-80 legislative session, the agricultural community successfully lobbied for a rate-cap on what SEWD could charge for its water fees and assessments, essentially assuring that the water district would never be able to build the infrastructure it needed on the back of the agricultural community. Given the marginal nature of many agricultural ventures, it is not surprising that this rate protection legislation was written into law.

Other political actions and issues that help create the current ‘challenge’ in Eastern San Joaquin County include:

1. Some in San Joaquin County applaud the defeat of Auburn Dam and the extension of the Folsom South Canal into San Joaquin County. This project would have provided still needed flood protection for the City of Sacramento, and allowed Eastern San Joaquin County to have a reliable surface water

supply off of the American River. It is difficult at this date for SEWD to share in the joy of the few that applaud this defeat.

2. When the SEWD treatment plant was constructed 30-years ago, the contract governing its operation was structured to fund only actual costs of operation. The last 30-years have been unnecessarily tense as a result of the contract terms, which has resulted in ulcers not only in individuals but in all the organizations involved. The nit-picking and lawsuits have not been fun. Fortunately, recent understanding of this tragic document has led to a possible solution to this issue.
3. With lack of surface water from the American and Mokelumne Rivers, SEWD was asked by USBR to be one of two CVP contractors on the Stanislaus River. A 1983 contract resulted in SEWD investing $65million on a conveyance system for this water. SEWD continues to spend about $500,000 a year trying to get USBR to honor these contracts. Fortunately, SEWD has been able to use this conveyance system for purchased water from understanding and cooperative local irrigation districts. To say this CVP contract has been a nightmare would be an understatement. Progress in 2009 is encouraging, but SEWD has not yet satisfied that it will receive reliable deliveries from the Stanislaus River.
4. With a new Board of Directors in 1998, and a new manager in 1999, SEWD changed its direction from one of being a malcontent to one of communicating and building partnerships. Working with the City of Stockton, SEWD proposed a local initiative that would have removed the agricultural rate-caps and allow for the construction of surface water distribution systems. The negotiations started with the City wanting to take over the DWTP and ended with the City providing the water district with funds to build the infrastructure it recommended at the time. Early on in the debate, the mayor of the City was quoted in local newspapers saying that he wanted ‘a divorce’ from SEWD. From that low-point, SEWD and its urban contractors have built a sound relationship that is now expected to thrive. The City’s need for a defensible general plan and to issue will-serve letters became a very good reason for the relationship to improve. SEWD also made concessions. We now have a ‘trust but verify’ relationship; a significant accomplishment.
5. The district has been mired in litigation for the past 15 years; litigation against the United States demanding increased water supply allocations; litigation between the urban area customers and the district over expenditures. Current policy changes are expected to reduce the amount of litigation over time.

Figure 11. SEWD in the 2002 Newspaper

One of the primary difficulties of the district stems from one of its greatest strengths: the fact that it is both urban and agricultural. The two service areas have different needs, financing capabilities and philosophies. Reasons for many Urban and Agriculture approach differences are probably obvious. How each group of individuals deals with land-use, budgets, regulations, missions, goals and objectives, differ vastly and should not be expected to be compatible. However, when it comes to the quantity and quality of groundwater, attitudes are similar and provide common objectives and a basis to support SEWD's management of the Basin approach.

From SEWD's experience, the challenge has been how to get both the urban and agricultural interests to support a sustainable water supply plan into the future. Both interests line up behind the benefits of conjunctive management of surface and ground water and the need to provide a sustainable water supply. The questions of who benefits and who pays for specific projects creates the controversy and challenges.

Examples of past Urban concerns:

1. How would these projects limit our ability to gain independence from SEWD?
2. Why should urban rate-payers be expected to pay the lion's share of the cost?
3. Can't the agricultural community pay a fair share?
4. Why can't we rely on only our portion of the Basin? [see figure 11]
5. The Urban area practices water conservation and if the Ag area did the same there would be plenty of water for Ag, Urban and the environment.

Examples of past Agricultural concerns:

1. How reliable will the surface water be, and how much will it cost?
2. Even if I have access to surface water, how can I afford to keep both the surface water and groundwater infrastructure maintained and operational?
3. Will the quality of surface water affect my crops?; how about my costs?

4. It is so easy to turn on my well, why would I want to change? Wouldn't it be easier and more cost effective to let others convert to surface water?
5. Why should I pay for groundwater recharge? Will I really benefit from more reliable groundwater levels and quality or will the urban area receive a greater benefit?
6. If I associate with SEWD, will they bring my operation to bankruptcy?

COMMUNICATION & POLICY MANEUVERS & CURRENT APPROACH

When the customer knows just as much about the Basin challenges as the professionals they hire to address the problems, it is important to listen carefully to what the customers believe are the solutions.

Ten years ago, SEWD was faced with the task of putting together a project to provide surface water to lands currently irrigating with groundwater. Using traditional methods from many years of experience, SEWD approached both agricultural and urban leaders and proposed solutions. Due to conflicts of the past, poorly-written contracts, and other regulatory and financial challenges, progress was dismal for the first few years.
It took awhile before SEWD realized that the key to building agricultural infrastructure was to use funding schemes that did not require raising water rates on SEWD agricultural customers. This approach was driven by the policy of the agriculturally dominated Board of Directors elected to manage the SEWD. Understand that this statement is not a criticism of these elected officials. It is simply a statement of fact that the reality to the agricultural community is that no matter how much water rates are raised, there is not enough revenue that can be generated to support the infrastructure improvements needed to resolve the Basin's challenges. This of course continues to be a concern with some in the urban portion of the SEWD. If an urban customer feels they are 'subsidizing' agriculture it is difficult to convince them otherwise. What eventually convinces most is the reality that there is only one groundwater Basin shared by both SEWD agriculture and urban customers, and that the overdraft in both areas must be addressed before the Basin as a whole recovers, or becomes sustainable.

The Basin is a confined, fairly homogeneous aquifer bound by the foothills of the Sierra-Nevada Mountains and the Stanislaus, San Joaquin, and Mokelumne Rivers. Over-pumping in one portion of the Basin creates an overdrafted area, setting up a hydraulic gradient for water from other parts of the Basin to begin migrating to the overdrafted area. Studies conducted over the past 30-years have shown that this is exactly how the Basin reacts. As expected, if recharge of a portion of an overdrafted basin occurs, groundwater levels will endeavor to reach a state of equilibrium benefiting a much larger area of the Basin than just the immediate recharged area. As stated previously, the 'in-lieu' efforts of the urban area (operation of the existing and future DWTPs) are expected to create a hydraulic barrier to further migration of saline contaminated water from under the western boundary of the Basin.

The problem now faced by the urban customers of SEWD is that the surface water banked under the City of Stockton may create water quality issues, and could be useless to the urban area as drinking water without further treatment. Therefore it is essential that the district have access to banked water in a location where it can be treated to drinking water standards before delivery to the urban area. To solve this problem, SEWD needs to bank surface water in the agricultural area, where recovered water from the bank can be delivered to SEWD's drinking water treatment plant (DWTP). The urban area generally understands the benefit of building an agricultural surface water distribution system if it is designed to deliver banked surface water to the DWTP in their times of need. This is expected to be the long-sought solution to provide a project that achieves a sustainable reliable water supply for our region:

- ✓ Recharge takes place in the agricultural area where the groundwater overdraft is the most severe.
- ✓ The urban area finances the distribution system required to accomplish recharge.
- ✓ The urban area receives the benefit from stored water in dry years when needed.
- ✓ The Basin benefits from the overall increase in groundwater levels and protection from further saline intrusion.

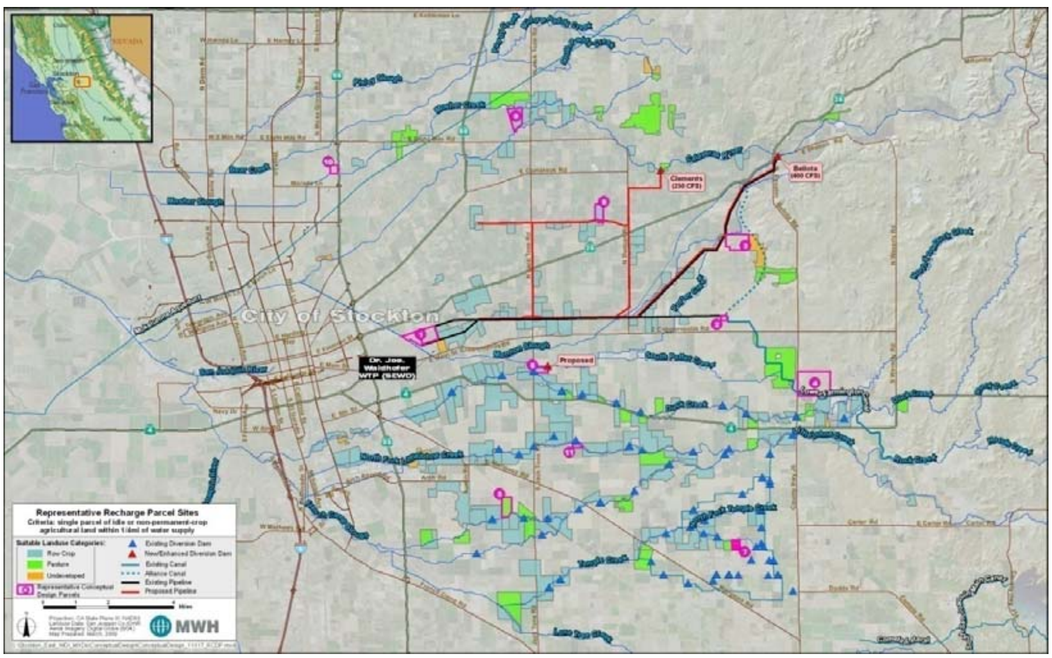


Figure 12. Proposed Farmington Program Phase II Conveyance and Groundwater Storage

So the 'push-back' experienced six to ten years ago has decreased as SEWD has learned the agricultural-urban dynamic that was facing the water district. The successes and progress made is a direct result of the diligent work effort of the Board of Directors, legal and political consultant, involved members of the public, and staff.

All attempts tried other than the current approach described above kept turning SEWD's focus back to the inability of the agricultural community to afford the infrastructure, and the urban community's demand for a sustainable reliable supply of drinking water.

SEWD is prepared to continue to adjust its approach in working with Agricultural and Urban leaders and interest. SEWD is optimistic that it can continue with the progress made, and is confident that the ‘fruits of these efforts’ will be ‘harvested’ for the generations that follow us in the service to our region and communities.

LOOKING FOR INPUT FROM THE EXPERIENCE OF OTHERS

SEWD is interested in your experiences, and what we may be able to learn from your attempts to address similar challenges in your communities. Please either provide them today for all to hear, or send me an email describing your experience. I would be more than willing to establish a blog to continue discussion on this topic for the benefit of all.

ACKNOWLEDGEMENTS

SEWD appreciates the suggestions that improved this document provided by Past President of the SEWD Board of Directors and current Division 4 Director Melvin Panizza, SEWD General Counsel Jeanne Zolezzi, Ken Steele, formerly with the San Diego County Water Authority, Ali Elhassan of Robertson-Bryan, Inc., Steve Knell, General Manager of OID. Thanks also to SEWD Engineering Technician Carina Solorio for her graphic expertise, and to Steve Knell of OID and Steve McCauley of West-Yost for encouraging that SEWD participate in this Conference.

RISING TO THE CLIMATE CHALLENGE

Murray Smith[1]

ABSTRACT

Agriculture dominates economic activity within Australia's Murray-Darling Basin, with 41 percent[i] of Australia's gross value of agricultural production[ii] generated from the basin and about two-thirds of this total production exported[iii]. Historically low rainfall has resulted in cutbacks in irrigator water allocations, urban water restrictions and reduced environmental flows.

A key element of the Victorian Government's response to water scarcity has been to establish the Northern Victoria Irrigation Renewal Project (NVIRP) to plan, design and deliver a program of works that will modernize the Goulburn Murray Irrigation District (GMID). NVIRP is being funded by the State Government $600M AUS, urban water users $300M AUS, GMID water users $100M AUS and Australian Commonwealth Government $1 billion AUS.

Modernization of the GMID irrigation distribution system will increase the standard of water delivery service to its customers, providing near-on-demand water delivery on-farm and a better managed delivery system for operator Goulburn-Murray Water. The project will reduce system losses (currently 780 to 870 GL per annum on average) and is anticipated to generate up to 425 GL of long term average annual water savings.

This paper discusses the five core elements of the modernization program:

1. Automation of the main backbone channel system
2. Farm to backbone connections
3. Upgrading metering technologies
4. Water savings
5. Challenges of investing in modernizing irrigation assets and environmental flows simultaneously.

INTRODUCTION AND BACKGROUND

The Murray Darling Basin, highlighted in Figure 1 below, is the principal agricultural production area of Australia.

[1] Chief Executive Officer, Northern Victoria Irrigation Renewal Project (NVIRP), 461 Wyndham Street, Shepparton, Victoria, Australia 3630, murray.smith@nvirp.com.au

Figure 1. Murray Darling Basin

For the 2008-09 water year (June 2008 to May 2009) inflows to the major storages in the connected southern Murray Darling system were the third driest in 118 years of records (1,860 GL). This followed the seventh driest year in 2007-08 and the driest on record in 2006-07 (970 GL) [iii]. The long term annual average is 8,840 GL (excluding inflows from the Snowy system and Menindee Lakes). The consequences of these conditions are shown in volume storages as displayed in Figure 2.

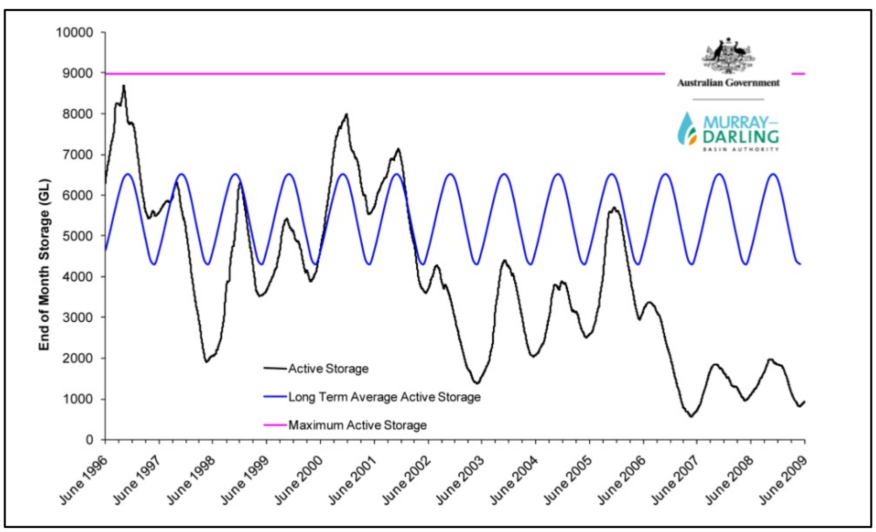


Figure 2. Murray Darling Basin Southern Connected system storages, June 1996 to May 2009

To address these and other climate related impacts, in 2004 the Victorian State Government (one of the four riparian states in the Murray-Darling Basin) formulated a long-term plan for water – *Our Water Our Future*. In June 2007, the Victorian Government announced *Our Water Our Future – The Next Stage of the Government's Water Plan*, a $4.9 billion AUS investment in major water infrastructure, including a number of projects to enhance water supplies in the Victorian part of the southern Murray-Darling Basin. A key component of this initiative is the Northern Victoria

Irrigation Renewal Project (NVIRP). NVIRP's function is to plan, design and deliver the program for modernizing the Goulburn Murray Irrigation District's (GMID) irrigation infrastructure which covers an area of 65,000 km^2.

NVIRP is both the name of the project and the entity delivering the program. NVIRP works closely with the asset owner, Goulburn-Murray Water (G-MW) in rolling out its works program. NVIRP also works closely with other State Government Agencies, Shire Councils and industry and community groups.

The GMID is the single largest user of water in the Murray-Darling Basin, diverting on average 2,780 GL per annum. It is an integral part of Australia's major food producing region. The GMID supports 30 per cent of Victoria's gross value of agricultural production. The estimated value of farm gate irrigated agricultural commodity production from properties supplied through the GMID channel system was $1.4 billion in 2005/06 from a state total of $8.5 billion. Irrigated agricultural production in the GMID is diverse: however, a number of major industries account for the majority of the farm gate output. Dairy production is the largest single contributor to the regional economy, followed by livestock production, fruit production, fodder crops and vegetable production. The estimated farm gate value of agricultural production for the major commodities produced in the GMID channel districts is shown in Figure 3.

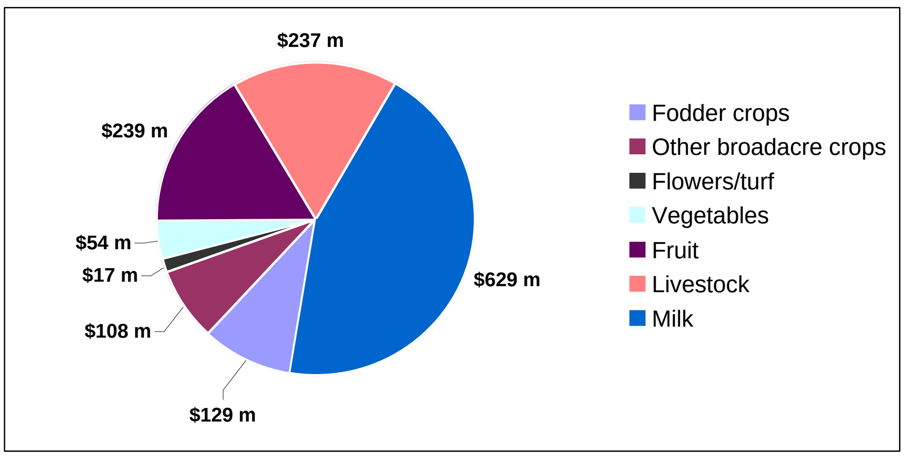


Figure 3. Local value of agricultural commodities produced – GMID 2005-06[iv]

Much of the GMID channel system was built almost 100 years ago and significant water losses, equivalent to 30 per cent of the water in the GMID, are experienced as a result of system inefficiencies such as leakage, seepage and evaporation in channels, meter inaccuracies and outflows at the end of channels.

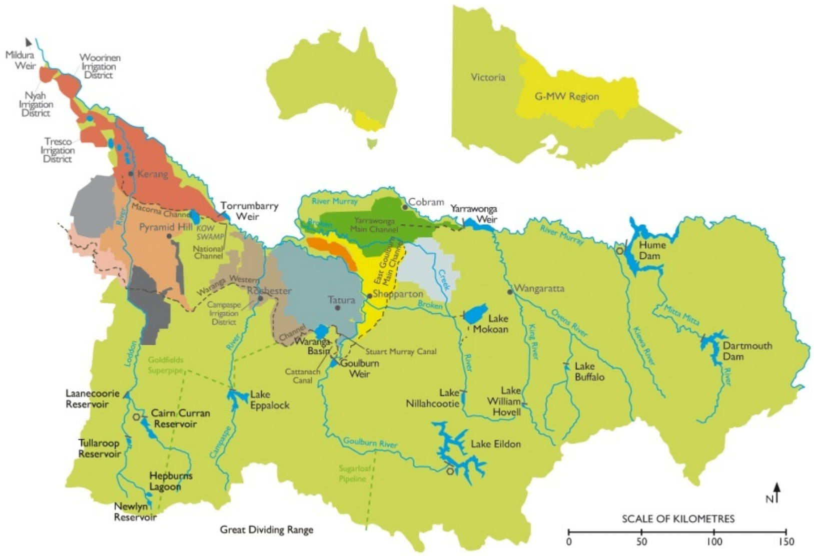


Figure 4. Map of the GMID in Victoria, Australia

The Project aims to recover water lost through leakage, seepage, evaporation and system inefficiencies via:

- channel lining and pipelining of channels
- automation of channels across the GMID
- metering rationalization and upgrades
- reconfiguration (i.e. decommissioning channels and realigning the historical layout of the irrigation channels).

Modernization aims to increase irrigation delivery efficiency from approximately 70 per cent to at least 85 per cent and effectively capture at least half of the current system losses. This project has drawn on experience from existing water savings projects in Victorian in the Goulburn system, the Macallister Irrigation District and in Coleambally in New South Wales.

Stage 1 of the NVIRP Project involves an investment of $1 billion (AUS) to modernize infrastructure within 58,500 km^2 of the GMID. Modernization of the GMID irrigation distribution system will:

- increase the standard of water delivery services, providing more uniform flow, increased supply to provide better control of water across surface irrigated land, shorter water ordering times and more efficient land use by removing redundant channels and structures
- lead to increased farm gate productivity and profitability and improved irrigation application efficiency, thereby assisting farmers with market competitiveness
- reduce system losses, allowing more water to be used for productive and environmental purposes.

At a national level, the Australian Commonwealth Government *Water for the Future* program aims to secure the future of irrigation communities and improve river health in the Murray-Darling Basin. The program aims to provide funding to significant state-based water infrastructure projects, in order to address climate change and reduced water availability. Subject to due diligence and the delivery of half of the water savings gained as additional flows to the environment, the Commonwealth Government has committed to contributing 90 per cent of the total project costs for Stage 2 of the NVIRP project, up to a maximum funding amount of $1 billion (AUS). Stage 2 will build upon Stage 1 by extending modernization works across the full extent of the GMID system.

The Commonwealth Government recognizes that Australia faces major challenges in ensuring sustainable water supply in the face of drying climate and rising demand for water. In response, the Australian Government's framework, *Water for the Future* ($12.9 billion AUS over 10 years), provides national leadership in water reform for all Australians. *Water for the Future* is built on four key priorities:

- Taking action on climate change
- Using water wisely
- Securing water supplies
- Supporting healthy rivers.[v]

Investment in Stage 2 of NVIRP is expected to generate up to an additional 200 GL of long term average annual water efficiency savings, to be shared equally between the Commonwealth Environmental Water Holder and GMID irrigators.

In addition, $3.1 billion of the $12.9 billion AUS has been committed to buying back water entitlement under the Commonwealth Government's program, *Restoring the Balance in the Murray-Darling Basin*.

MODERNIZATION OF THE GMID

NVIRP has three core objectives:

- to promote the sustained viability of the GMID as the Murray-Darling Basin's major food production area
- to create an irrigation supply system that meets world's best practice and maximizes its resilience in the face of climate change
- to generate water savings for productive use and enhance environmental flows.

These core objectives are integrated and delivered through NVIRP's investment in the modernization of the supply system for the GMID.

Defining and Automating the Channel Backbone

Overall there are approximately 6,300 km of earthen channels in the GMID, which makes it Australia's largest irrigation channel network.Works associated with modernization of the larger carrier and trunk channels, which form the core 'backbone' from which farm connections will be based, include:

- automation of channel control structures
- strategic measurement of off-takes and outfalls on the backbone
- rationalizing and upgrading regulating structures and other structures as required to avoid modernization costs and reduce ongoing operation and maintenance costs
- improving the standard of water supply service
- channel bank and bed remediation and lining where appropriate to generate water savings and restore the integrity of the system
- automated structures controlled by centralized predictive software - Total Channel Control® systems (TCC®). This in turn reduces system outfall and generates water savings.

Data captured through TCC® and additional pondage testing is improving the quality of the water balance, further informing NVIRP's investment decisions as works are better targeted at recovering water losses and service enhancement. To determine the extent of the existing channel system to be retained as the modernized backbone, a methodology has been developed that assesses a number of attributes relevant to the future of irrigation in the region (see Figure 4). These include:

- Channel capacity utilization as defined by Delivery Share
- Land suitability for sustainable irrigation
- Location of large water use businesses
- Location of Prime Development Zones (PDZ) (i.e. those areas with good soils and topography)
- Reconfiguration program outcomes and targeted outcomes
- Consultation with Goulburn-Murray Water area operations staff
- Consultation with customer Water Service Committee and Modernization Committee members.

The methodology recognizes that the concept of modernization affords the opportunity to analyze future infrastructure requirements against tailored water supply services. In the future, it is anticipated that water supply services will include gravity and pressure irrigation (with various levels of command), domestic and stock supplies and, in a small number of cases, no service (or removal of service). These services will most likely be provided by a blend of public (modernized backbone) and private infrastructure but will predominantly be private channels.

To ensure the objectives and principles of the NVIRP are met, it is necessary to reduce the extent of the backbone to cost effectively facilitate the desired outcomes of the connections component of NVIRP and fit within the project budget.

Following examination of accumulated Delivery Shares along each channel within the channel system, the channel cut off point using Delivery Shares is to be applied to those channels or sections of channel with greater than 20 ML/d[vi] accumulated Delivery Shares, which currently equates to the equivalent to about 2,000 ML/year usage (based on the 270-day irrigation season).

To facilitate the determination of the extent of backbone a generic procedure has been developed and applied uniformly across the project footprint. This generic procedure is shown in the figure below.

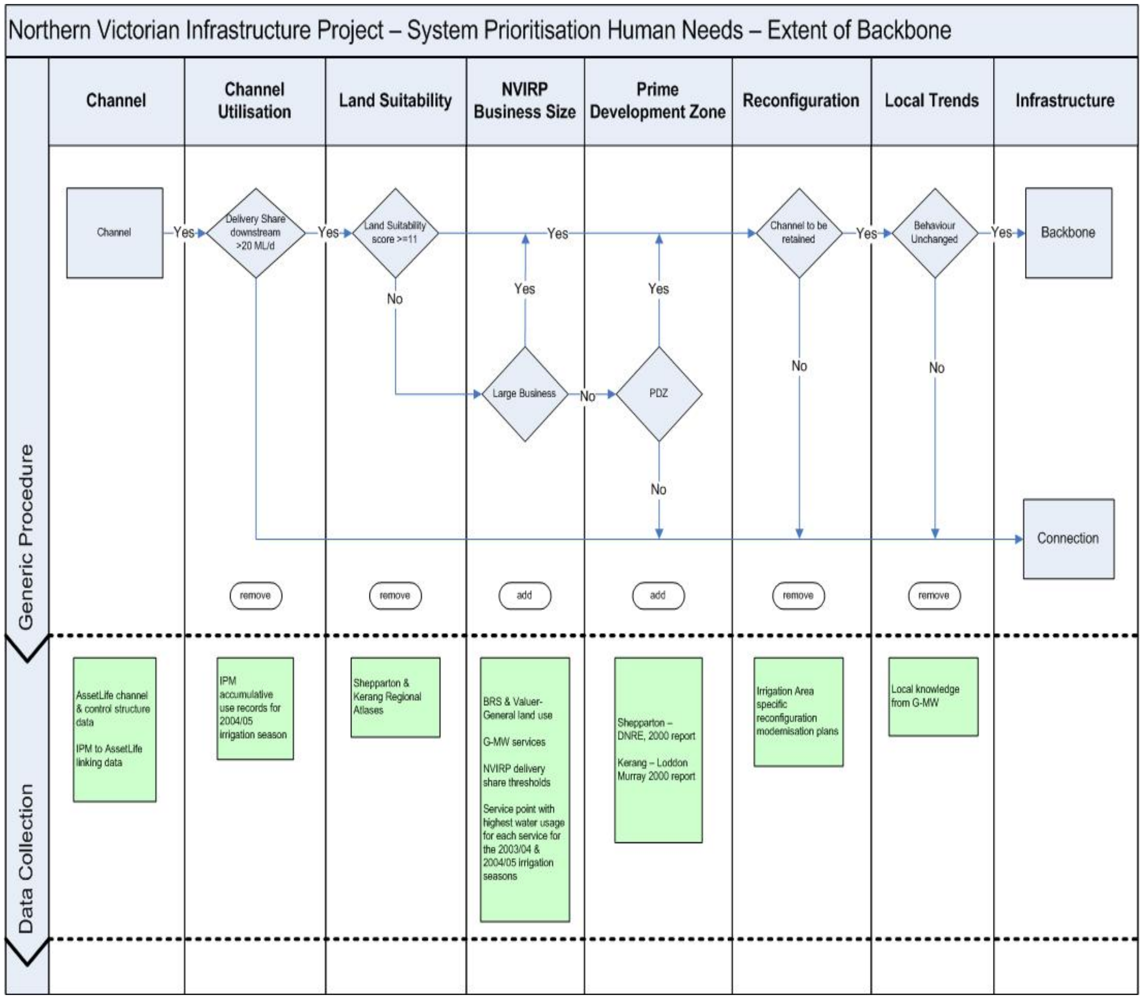


Figure 5. NVIRP – Decision Tree for Determining the Extent of the Modernized Backbone

To reduce the risk of redundancy, the modernized backbone needs to supply more than one farm. Therefore, two large mixed farms were considered the smallest unit (to give the same service across the region), which meant a required minimum channel capacity to meet the needs in delivering approximately 2,000 ML of water entitlement per annum (i.e. 20 ML/d Delivery Shares). There is a balance between extending the backbone further and reducing the average distance farmers on spurs need to go to access the backbone. Taking the backbone into small channels means the system can not deliver fit-for purpose services such as water near-on-demand and constant flows during irrigation.

Delivery Shares provide an irrigator a claim to the channel capacity to have water delivered to land in an Irrigation District and a share of the available water flow in a delivery system. Delivery Shares are linked to land and stay with the property if the

Water Share is traded away. Delivery Share may be traded to other landowners supplied from the same channel or to channel systems where capacity is available or relinquished.

To date approximately 2,900 km of the existing channel system has been defined as the backbone. Irrigators on the spur channels not included within the backbone will be targeted by the Connections Program which aims to remove public spur or distribution channels (i.e. those channels not included in the new Backbone) and enable the Backbone to be the prominent footprint in the GMID by:

- creating new direct connections to the backbone for those customers who are currently connected to spur channels
- relocating water supply points from spurs to the backbone
- removing water usage from spur channels
- removing spur channels from the public supply system.

Historically, some 60 per cent of the length of the irrigation supply system was comprised smaller spur channels. These generally provide a low level of service, and are leaky and costly to maintain.

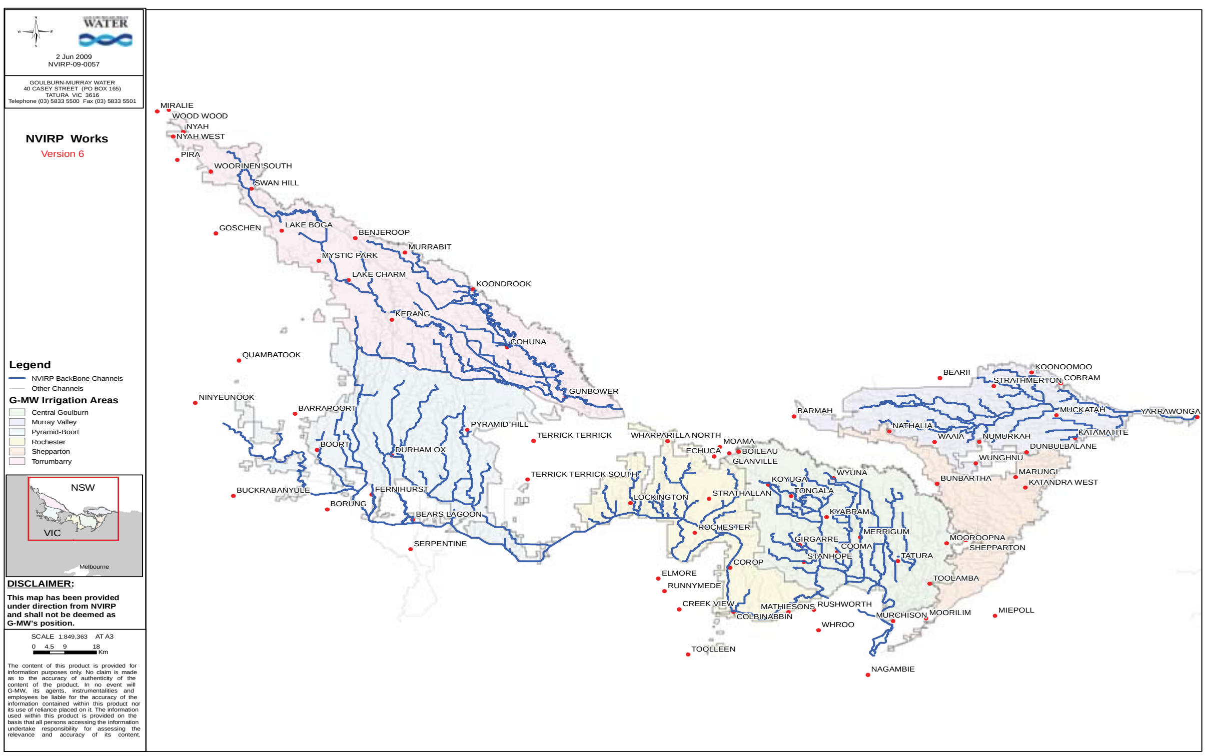


Figure 6. Backbone Channels

Connections Program

A key element of NVIRP is the Connections Program, which aims to generate in the order of 200 GL of long term average annual water savings and contribute to the delivery of a modernized irrigation system. This will be achieved by gaining landowner agreement to rationalize channels, transfer water Delivery Shares to the main backbone channels and reduce the number of service point connections to the backbone channel.

The main backbone channel comprises larger carrier and trunk channels, from which all service connections are to be based. Rationalization refers to making the system more efficient by concentrating connections on the backbone channels, instead of through a wide network of obsolete spur channels and infrastructure. Rationalization is also delivering a system that is affordable to customers.

Rationalizations are occurring to remove redundant infrastructure and create service points focused on accessing the main backbone channel. The Connections Program includes avoiding modernization costs by connecting properties to the backbone, rationalizing infrastructure and replacing or upgrading meters along the backbone. By connecting landowners to the backbone network of large modernized supply channels, the program can:

- develop and maximize rationalization opportunities, thus creating a cost-effective and affordable irrigation system through consideration of Whole of Life (Operations & Maintenance) cost implications. This is described further in Goulburn-Murray Water's *Impact of Modernization: Whole of Life Cost Analysis*[vii] report
- develop an incentive based payment offer that meets both the objectives of NVIRP and the landowner
- maximize connections from the backbone to improve levels of service
- help reach agreements for meter replacements on the backbone
- facilitate ongoing farm improvements
- generate water savings.

In essence, rationalization and connection opportunities involve the development of individual business cases and the offer of incentives to landowners through a negotiation process. Agreements are developed that meet the landholder's objectives whilst reducing the public irrigation supply network and associated costs to generate water savings.

<u>Farm Irrigation Assessment (FIA)</u> The FIA is a critical element of the Connections Program, delivered by Farm Designers engaged by NVIRP. The FIA process provides a fair assessment of on-farm connection costs, maximizes rationalization opportunities, informs landowners of their options and provides them with time to plan for change and make informed decisions.

The FIA process is also a methodical process whereby the Farm Designers work their way through a designated section of the channel system in a way that addresses avoided modernization opportunities that may exist and captures economies of scale and scope. It also helps assess connection opportunities for every landholder along a section of the channel system.

On-farm costs are incurred for any works that are required on-farm to reinstate the farm water delivery system, or ensure it continues to be operational, as a result of a change in the supply system servicing the property. To be eligible for on-farm cost incentives, the works must be necessary as a direct result of a new connection to the backbone, to avoid backbone modernization costs and/or the rationalization of spur channel infrastructure.

Incentives The objective of the incentive payments is to provide incentives to landholders to agree to the rationalization of infrastructure, reduce administration and internal audit costs, while ensuring a fair and transparent process that encourages on-farm investment, minimizes environmental risks and enhances regional development opportunities.

In essence, NVIRP is purchasing water savings, which results in reduced irrigation infrastructure and Whole of Life costs for the irrigation system whilst delivering on broader modernization objectives. To encourage on-farm changes, a portion of the incentive is withheld until all works have been completed as agreed.

Incentives are paid to individual landowners or groups of landowners to enable NVIRP to achieve its objectives under the Connections Program. There are three types of incentives available through NVIRP:

- Backbone Incentives - by rationalizing meter outlets and/or regulators on the backbone, avoided modernization costs and water savings are generated. This also reduces ongoing operation, maintenance and future renewal costs
- Connections Incentives - moving Delivery Share to the backbone results in water savings being generated as water delivery is metered through an accurate water meter
- Rationalization - decommissioning infrastructure results in water savings being generated and reduces ongoing operation, maintenance and future renewal costs.

Generally, a Connections Incentive involves the transfer of Delivery Share from an existing service point to a new/modernized service point location on the modernized backbone channel. This may also involve the privatization or rationalization of irrigation assets, including channels, culverts, regulators and other structures. Incentives are available for each kilometer (or part thereof) of channel removed (less direct project costs). The incentive packages are designed to encourage connections to the backbone as the highest priority. A key point of the incentive package is that the value that can be offered to a landholder is determined by the scale of the on-farm works required to re-connect an irrigation supply, not the value of the water savings an individual business case generates.

Improved Metering of Supplies

Currently water is delivered to Goulburn-Murray Water customers through approximately 24,500 discrete service points (or outlets). Approximately 65 per cent of these service points are metered using Dethridge Wheel meters. Dethridge Wheel meters have served the industry well over a long period of time; however they will not meet the new Australian National Metering Standards as with regard to field accuracy of +/-5 per cent. Goulburn-Murray Water in-situ meter testing has shown the potential for one Dethridge meter to deliver nearly 25 per cent more than the neighboring meter. Dethridge wheels also have inherent Occupational Health and Safety issues and are prone to tampering.

Domestic and Stock small volume users account for 30% of all service points. The NVIRP metering program aims to facilitate water management and accountability, detect unauthorized use and improve water savings. The ability to accurately measure water will also encourage improved on-farm water use efficiency and support improved off-farm water supply system efficiency. As part of the NVIRP implementation all service points on the backbone channels will be metered with accurate meters.

As part of its implementation process NVIRP will provide landowners with choice in terms of their:

- number of service points
- service point location
- distribution of Delivery Shares between service points
- on-farm infrastructure size
- design flow rates
- type of meter.

A number of service points installed over the last 50 plus years are no longer required due to farm amalgamations and the nature of farming changes. This trend is expected to accelerate. To minimize the cost of meter replacement and reduce the number of replacement meters that will not be fully utilised in the longer term, NVIRP is putting significant effort into service point rationalization/decommissioning. This effort is supported by a strong meter related communication strategy and by providing financial compensation and supporting the introduction of cost-reflective tariffs.

A large number of the new meters being installed have a range of enhancement features including remote operation for larger outlets, which can influence the performance of TCC® and remote read for smaller outlets. Domestic, stock and other very small outlets will remain local read only. The level of enhancement is largely based on the impact the service point/outlet may have on service levels of other customers and the operation of the system delivery channels. The remote operate and remote read outlets also have the capacity to build in additional features such as automation of on-farm systems and irrigation scheduling technologies.

WATER SAVINGS

Water savings are being systematically generated as the project is rolled out. These savings are a combination of fixed and variable elements, with the variable elements largely linked to annual water right allocations. Installation of TCC® is reducing outfall losses. Targeted channel lining is reducing both seepage and leakage losses. The Connections Program with the rationalization of entire channels and related structures is generating a range of savings including removing evaporation losses. Installing new service points with new meters that have no systematic measurement bias will create high durability water savings due to improved meter accuracy and improved engineering standards on gate seals and concrete cutoffs, which will reduce supply point leakage.

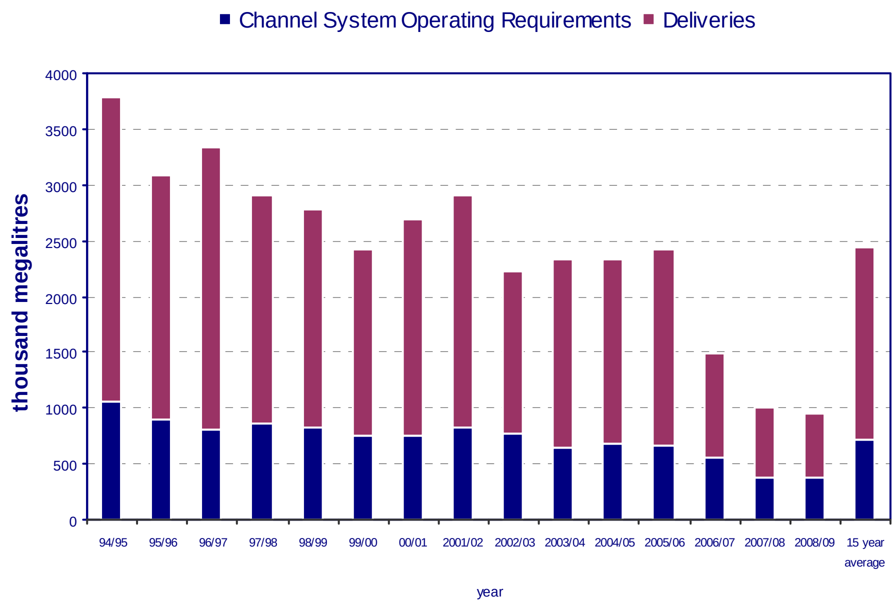


Figure 7. GMID Channel System deliveries and losses (1994/95 to 2007/08)

Water savings are effectively being generated by reducing system operating losses. Figure 7 highlights that whilst water deliveries have varied significantly over the past 15 years, system operation losses have been relatively stable. This is notwithstanding the last few years, where in response to drought some channels have not been operated at all while other have operated below design operating level in efforts to maximize what water is available.

The water savings generated will be independently audited at the end of the irrigation season in May. These savings will be shared with urban users in Melbourne, system irrigators and to benefit environmentally impacted wetlands and waterways. However, the Victorian Government's stance to take water saved from north of the State to the south has evoked a similar emotional outcry as has been seen in California.

Figure 8 below provides an overview of the annual water allocation process whereby system operating losses must be covered before customers can receive any allocation towards their water entitlement rights. By reducing system operating losses customers (including the environment) will receive more water earlier in the irrigation season than is currently the case.

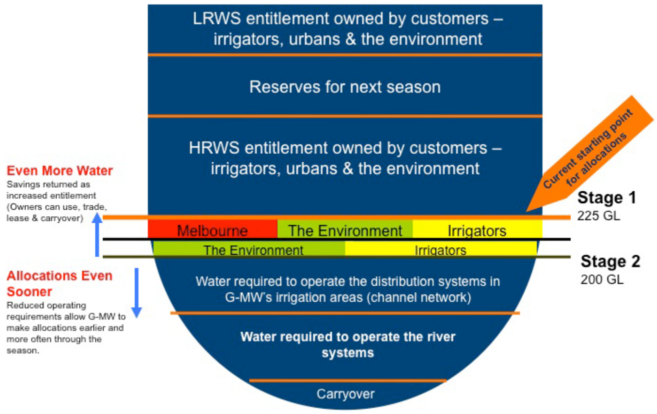


Figure 8. Delivering more water sooner through modernization
LRWS = Low Reliability Water Share, HRWS = High Reliability Water Share

SYNERGIES BETWEEN WATER PURCHASE AND INFRASTRUCTURE MODERNIZATION INVESTMENT

The Commonwealth Government's Department of Environment, Water, Heritage and the Arts (DEWHA) is responsible for administering the Commonwealth's water rights or entitlements purchase/buyback scheme under its $3.1 billion (AUS) program, *Restoring the Balance in the Murray-Darling Basin*. *Water entitlements* [acquired under this program] *will be used to protect or restore environmental assets such as wetlands and streams*[viii].This activity generally uses an open tender process as the principal mechanism of purchasing water entitlements. The very scale of purchases is creating significant distortions in the water market. This is evidenced by the average purchase price being paid by DEWHA against prices being paid in areas that do not have access with a price differential of approximately $500 AUS/ML of entitlement.

As at September 2009 DEWHA's market activity commands 58 per cent of the total trade and up to 77 per cent in one key sector. This is liable to distort the market, particularly when that major purchaser is not driven by commercial pressures to validate a market value by reference to economic criteria – i.e. the ability to generate future revenue from irrigation from the use of that resource. The Victorian Government has had in place for some time a four per cent trading cap on the permanent sale of water entitlements out of irrigation areas. Whilst recognizing the importance of water trading markets, the capacity for communities to adapt to changing water environments was seen as critical.

Untargeted Buyback

Implementation of Buyback as a stand-alone untargeted program by itself has the potential to generate the following outputs and outcomes:

- a Swiss-cheese effect, with a scattering of de-watered properties across the landscape with no linkage to a coherent regional plan for future optimal land-use

- an increase in the cost of future infrastructure reconfiguration as the remaining irrigation properties are located randomly across the region
- undermining of the value of the investment in modernized infrastructure when water is purchased directly from the new automated backbone
- higher unit costs for the remaining water users
- reduction in productivity where water is taken from highly productive soils ideally suited to irrigation with low environmental impacts, while leaving other less-desirable areas still heavily irrigated
- eroded community confidence in the process, who see little coherence or commitment to the bigger picture and longer term viability of the region.

Targeted Buyback

By contrast targeted purchase of water entitlement, combined with investment in infrastructure reconfiguration has the potential to generate significant synergies and support NVIRP's wider objectives. This targeting could yield the following outcomes:

- a reduction in demand on legacy spur channels. A Buyback target of 300GL would represent some 50% of the remaining water share located within spur channels
- buyback of water from spur channels helps promote system rationalization and will generate consequential water savings from closure of redundant channels and removal of older meters that under-record
- reduction in the costs of future connections. Where the water buyback is sourced from properties that are distant from the backbone this helps lower the average cost of new connections, as it reduces the number of high-cost, distant locations
- increased productivity on average across the irrigation district. Where the water is sourced from lower productivity areas and smaller properties Buyback helps promote overall productivity gains, as more of the water used on larger properties able to generate higher returns on better soils
- reduced environmental impacts. Where the water is sourced from areas with high environmental impact from salinity, then the purchase will help promote the sustainable future of the supply system by reducing demand in higher risk areas and increasing associated eco-system services
- greater social cohesion. Communities are willing to support water trading and buyback where they can see that it forms part of a coherent plan that takes account of associated implications for the economy, the environment and society.

For these synergies to be realized it will be important to target the application of Buyback to those locations that will yield multiple benefits.

Supporting Evidence from Commonwealth Scientific and Industrial Research Organization (CSIRO)

Research by CSIRO confirms that integration of government water purchases with a wider reconfiguration exercise through 'spatial targeting' generates significant benefits.[ix]

With targeted buyback and land reconfiguration in just one of the six irrigation areas (Torrumbarry Irrigation Area) of the GMID, the value of ecosystem services was increased by up to $463.7M (AUS) against the base case through the generation of:

- 61GL of water for environmental flows
- sequestration of 10.6M tones of CO_2e/yr through reforestation
- 13 EC reduction on river salinity
- 24% increase in the value of agriculture production

Without a targeted approach to planning, the 20 per cent reduction in water for irrigation could result in a loss of $68.7M (AUS).

Agreement between the Commonwealth and State Governments

Under a new agreement between the Victorian State Government and the Australian Commonwealth Government it is proposed that some 460 GL could be purchased from the GMID through the Buyback program over a five year period. That is equivalent to 25% of the total available entitlement.

At the core of the cooperative model adopted by the State and Commonwealth Governments is the intent to maximize synergies between the program areas of both Governments such that:

- value for money investments are made in modernized irrigation infrastructure
- communities are provided time and resources to adapt to a changed water environment
- communities and industries are left more resilient to the impact of climate change.

As a result of the *Water for the Environment Agreement* between the Commonwealth and Victorian Governments, the Northern Victoria Irrigation Renewal Project (NVIRP) in conjunction with other stakeholders has established exemption criteria to allow permanent trade out of irrigation areas to the Commonwealth Government, irrespective of the 4 per cent Trading Cap. These criteria have at their core four elements.

<u>Complements the NVIRP Modernization Program</u> – results in a reductionin the public irrigation footprint (rationalizes assets and drives down the whole-of-life costs), generates water savings, improves the water delivery service and increases the affordability and security of irrigation for those that wish to remain in the industry into the future.

<u>Generates sound land and water management outcomes</u> - complements Land and Water Management Plans, generates beneficial environmental outcomes, and promotes sound irrigation practices.

Is fair, transparent, and open – provides the irrigation community with the relevant information and the ability to seek support and advice prior to applying for an exemption and subsequent sale of water share to the Commonwealth.

Provides flexibility- provides the ability to adjust as circumstances change or key objective are achieved, and offers an avenue for all irrigation customers to participate if required.

Assessment Criteria include:

Irrigation suitability	Using soil type, salinity, environmental considerations, active floodplain, drainage provision, and salinity impacts to determine areas of the GMID that are unsuitable for irrigation.
Rural Land Use Change	Areas where land use change is occurring e.g. urban expansion.
Distance from Backbone	Distance from the modernized backbone channel network is a key consideration in ensuring ongoing affordability of irrigation into the future.

SUMMARY

The integration and scheduling of the NVIRP program of works is assisting to inform ongoing infrastructure investment decisions as a result of an improved understanding of the system's water balance.

The Connections Program is playing an important role in helping secure the future of the GMID by generating water savings as part of the Northern Victoria Irrigation Renewal Project and delivering on core modernization objectives including:

- Strengthening the long term viability of the backbone channel system
- Improving on-farm irrigation systems leading to increased productivity
- Reducing Whole of Life costs of the irrigation system through rationalization of redundant assets and ensuring the affordability of the modernized system
- Encouraging further regional development and on-farm investment.

It is apparent from the landholder participation rate that the Connection Program is attractive. This is further supported by the fact that less than two per cent of offers have been rejected.

Investment in modernization is delivering more water sooner to both water users and the environment and is assisting manage the impacts of climate change. A targeted approach to water Buyback will provide a better value for money investment. It will also provide enhanced environmental and social outcomes which support more resilient and enduring communities. Whilst buyback is a necessary part of the Murray Darling Basin reforms, investment in infrastructure which reduces system losses increases water available for consumptive purposes and the environment.

The joint funding arrangements facilitate the sharing of benefits across a generational project.

It is probable that the approach taken in Victoria Australia for the modernization of irrigation assets has applications elsewhere around the world with a purpose built entity able to draw together funding sources, engage with communities and key Government and other stakeholders.

END NOTES

[i] www.mdba.gov.au

[ii] Australian Food Statistics 2008, Food Policy Section. Australian Government Department of Agriculture, Fisheries and Forestry – *Agricultural production in 2008 valued at $35.2 billion AUS.*

[iii] http://www.dfat.gov.au

[iv] Australian Bureau of Statistics 2008 and RMCG July 2009

[v] http://www.environment.gov.au/water/australia/index.html

[vi] 1 ML/d = 1 million liters per day or 0.811 acre feet per day

[vii] Impact of Modernization, Whole of Life Cost analysis, 12 June 2009

[viii] http://www.environment.gov.au/water/policy-programs/environment/index.html

[ix] Crossman et al CSIRO (2009), *Reconfiguring an irrigation landscape to improve provision of ecosystem services*

COACHELLA CANAL LINING PROJECT: COST EFFECTIVE CONSTRUCTION FOR LARGE SCALE WATER CONSERVATION

Daniel Charlton[1]
Wayne Dahl[2]
Chris Dull[3]
Ken Steele[4]

ABSTRACT

The Coachella Canal Lining Project (CCLP), completed in 2007, is conserving over 26,000 AF of water per year. The project assists California in meeting its water needs while staying within its entitlement of Colorado River water of 4.4 million AFY and achieving water usage goals established under the Quantification Settlement Agreement. The project also provides water to settle a long standing water rights issue on the San Luis Rey River in California. To date, the total cost of the project is approximately $120 million including design, construction, environmental mitigation, and supervision and administration. Funding was provided by the California Department of Water Resources in the amount of $83.65 million, with the San Diego County Water Authority responsible for the remaining costs.

The Bureau of Reclamation completed construction of the Coachella Canal in 1948. The canal is operated and maintained by Coachella Valley Water District (CVWD). CVWD administered the design, construction, and environmental aspects of the CCLP. The project was designed and constructed in accordance with Reclamation standards and administered by the CCLP Coordinating Committee composed of CVWD, SDCWA, and a mutually agreed chairman with participation by Reclamation, the San Luis Rey Settlement parties, and other interested parties.

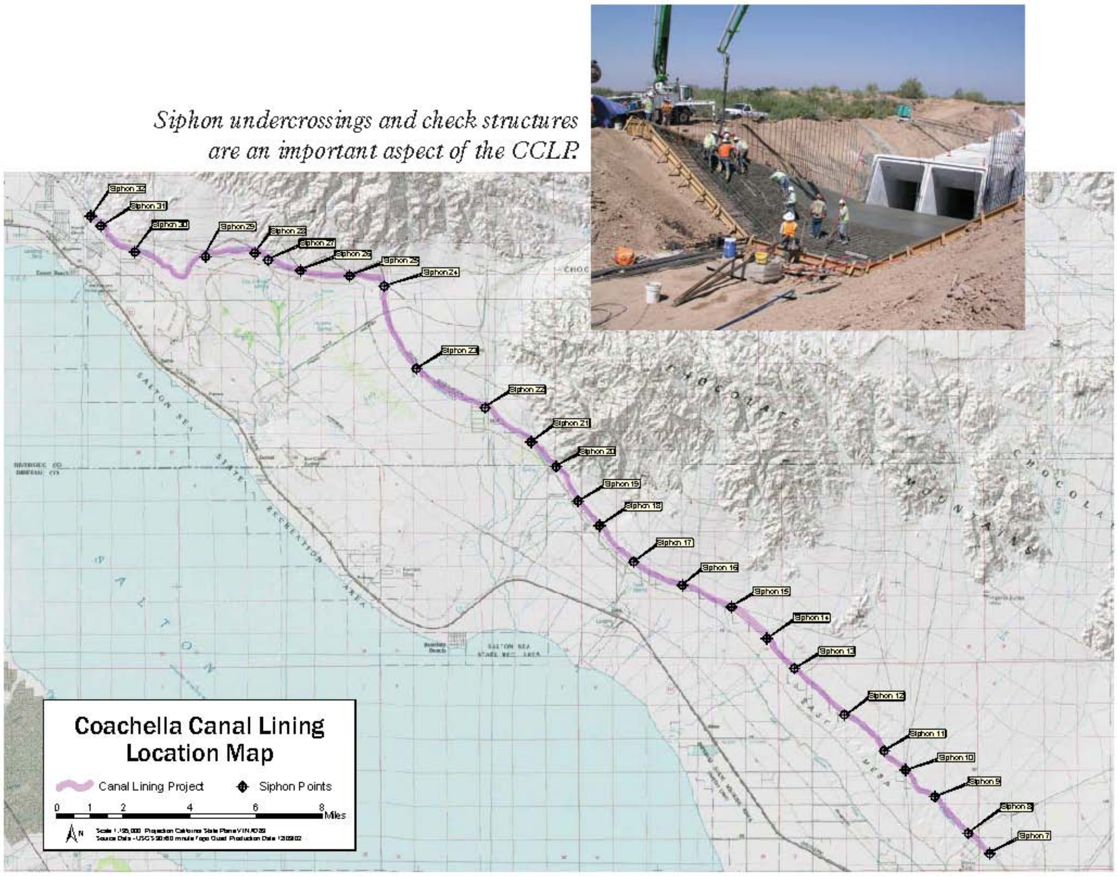
The CCLP lined approximately 36.5 miles or about one-third, of the 123 mile canal. The northern 38 miles of the canal was lined in 1948 during original construction and the southern 49 miles of the canal was lined in 1981 by the Bureau of Reclamation. The project was originally envisioned to consist of lining the existing canal section, however, following the 60 percent design review, the project was revised to construct a new adjacent parallel canal at significant cost savings. The project involved 5.7 million cy of excavation, 1.3 million sq yds of 3-inch thick concrete paving, construction of 25, 10.5 by 10.5-foot double barrel inverted siphons, six new check structures, over 60 miles of deer fence and 56 wild game drinkers.

[1] Engineering Manager for Irrigation, Storm Water, and Electrical, Coachella Valley Water District, P.O. Box 1058, Coachella, CA 92236; dcharlton@cvwd.org

[2] President, Dahl Consultants, Inc., 157 Parkshore Drive, Folsom, CA 95630; wdahl@dahlconsultants.com

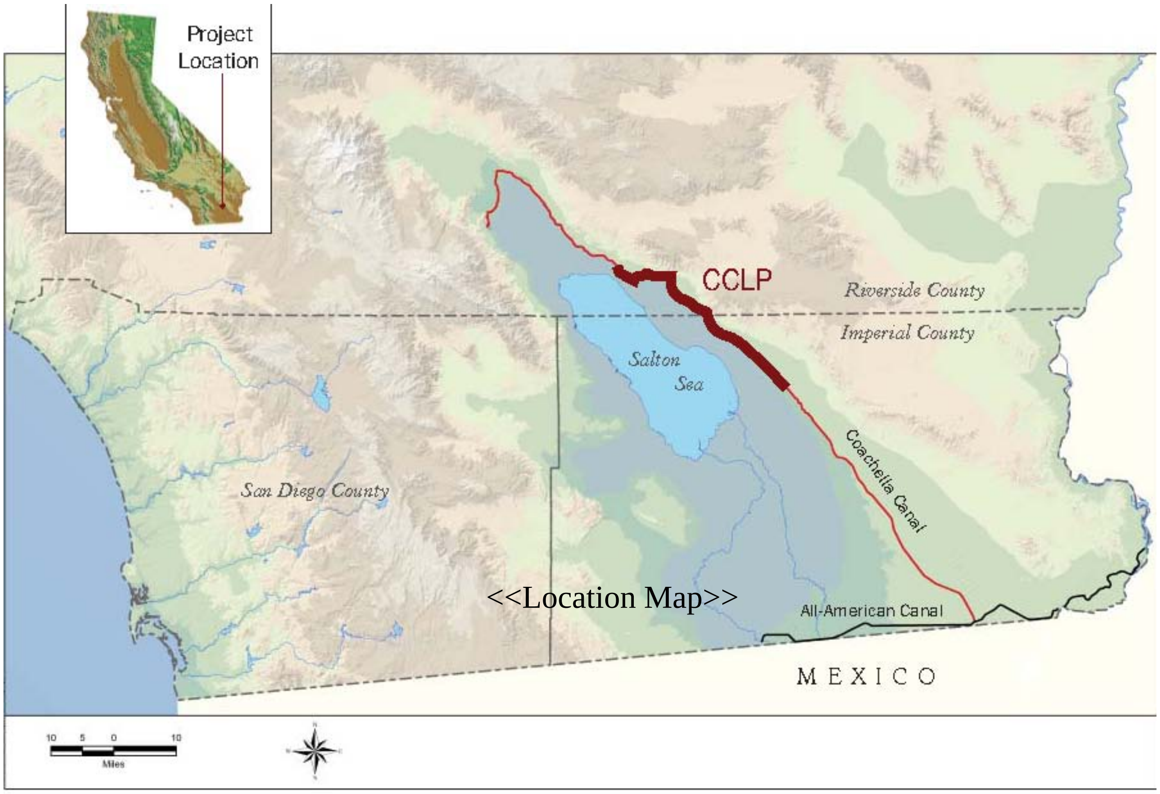
[3] Vice President, R.W. Beck, San Diego, CA; cdull@rwbeck.com

[4] Consultant, 1740 Burnside Way, Stockton, CA 95207; kensteele@sbcglobal.com (Engineering Manager, retired, San Diego County Water Authority)



HISTORICAL PERSPECTIVE

Located partially in Imperial County and partially in Riverside County, California, the Coachella Canal is situated between the Salton Sea and the Chocolate Mountain range. The canal headworks consist of a turnout on the All-American Canal located near the Mexico border, with the canal extending northwest 123 miles to the Coachella Valley. The Coachella Canal conveys Colorado River water to cities and agriculture north of the Salton Sea, within the lower Coachella Valley.



The Coachella Canal branches off the All-American Canal and extends 123 miles northwest.

The All-American and Coachella canals were authorized for construction by the Boulder Canyon Project Act of 1929. Although excavation for the Coachella Canal started in 1938, final construction was not complete until 1948 due to delays resulting from World War II. Only the last 38 miles of the canal were concrete-lined during the original construction.

Starting in the 1960s, several significant system improvements were made to the Coachella Canal including (1) installation of a supervisory remote control and telemetering system to operate the canal and distribution system; (2) construction of a regulating reservoir (Lake Cahuilla) at the terminus of the canal; (3) construction of two flood control dikes; (4) addition of 10 traveling de-mossing screens; and (5) construction of a new check gate and rehabilitation of an existing check gate. In the 1980s, the first 49 miles of the Coachella Canal were concrete-lined, leaving about 36.5 miles of the canal unlined.

The recent Coachella Canal Lining Project (CCLP) was developed as a water conservation action to comply with provisions contained in the 2003 Quantification Settlement Agreement (QSA). This historic agreement consensually settles longstanding disputes regarding priority use and transfer of Colorado River water. A QSA-related agreement, the Allocation Agreement, was entered into by the U.S. Bureau of Reclamation (USBR), Metropolitan Water District of Southern California, Coachella Valley Water District (CVWD), Imperial Irrigation District (IID), San Diego County

Water Authority (SDCWA), the San Luis Rey Indian parties, the City of Escondido, and the Vista Irrigation District. In addition to other objectives, the Allocation Agreement identifies the quantity of water to be conserved by lining the remaining portion of the Coachella Canal, and names the California Department of Water Resources (DWR) as the source of funding for the project.

The CCLP consisted of constructing approximately 36.5 miles of concrete-lined canal adjacent to the existing canal, which included 25 inverted siphon undercrossings (to convey rainfall runoff flows from the Chocolate Mountains accross the canal), one railroad crossing, six check structures, and a variety of consequential environmental mitigation measures.

In addition to the numerous construction components of the project listed below, at least five innovative and unique construction methods (discussed in a later section) were developed and employed during the project. The methods included using (1) contractor-designed and fabricated traveling forms; (2) a mobile sprinkler coined the "Dust-Abator"; (3) drain tile and sump system for dewatering; (4) a very large excavator; and (5) a multiple unit paving train.

Canal construction was complex and incorporated many components included clearing and grubbing, dust abatement, constructing a sediment control weir, pre-wetting canal and spoil excavation, compacting embankments, trimming earth foundation, placing concrete, installing safety ladders, constructing canal contraction joints, installing a road drain pipe, and replacing various existing pipelines. Canal construction also included reinforced concrete broad-crested weir flow measuring structures and canal tie-ins.

An important aspect of the project was construction of the siphon undercrossings and check structures, which included reinforced concrete transition structures, earthwork, roadways, riprap, sheet piling, safety cable and floats, metalwork and chain link fencing. Construction of check structures also included control buildings, stilling wells, commercially designed radial gates, complete with appurtenances, electrical and instrumentation.

Environmental mitigation was and continues to be important to the success of the project. Several environmental groups were formed with agency representatives to collaborate on solutions to unique environmental concerns. Environmental mitigation encompassed cultural resource surveys, construction monitoring, mitigation for aquatic and riparian habitat, desert riparian habitat, tree replacement, fishery mitigation, and large mammal monitoring and mitigation measures which included wildlife fencing and watering ponds located outside fenced areas to provide wildlife access to water.

Construction of the CCLP proved to be environmentally challenging. Mitigation measures included development of a 17-acre marsh; maintenance of Dos Palmas core marsh/aquatic habitat; 325.5 acres of desert riparian habitat; desert riparian re-vegetation; 2:1 tree replacement; animal fencing/drinking troughs; construction of a stocked fish pond; and an endowment for the long-term maintenance of mitigation land.

Through exceptional cooperation and resourcefulness among the project partners, the CCLP was built on schedule, within budget constraints, and with an extraordinary safety record. The CCLP included the proficient collaboration of multiple coordinating committees, consistent construction team meetings, oversight by project partners, and environmental management and stewardship to bring about a successful project.

PROJECT DESCRIPTION

The following table presents a comprehensive listing of project statistics.

PROJECT STATISTICS OF INTEREST	
▪ 26,000 afy of conserved water	▪ 525 human safety ladders
▪ 35 miles of concrete-lined canal	▪ 325.5 acres of desert riparian habitat developed
▪ 25 inverted siphon undercrossings totaling approximately 1.6 miles in length	▪ 875 acres private land for habitat
▪ 6 check structures, including gates and control buildings; solar power in 2008	▪ 17-acre created marsh
▪ **1,400 linear feet of pipe overcrossing**	▪ 1 fish pond stocked with fish
▪ 1.3 million square yards of concrete for 3-inch thick canal lining	▪ 3,500 linear feet of tortoise fencing
▪ 37,000 cubic yards of concrete for siphons and check structures	▪ 65,000 linear feet of chain link fencing
▪ 5.7 million cubic yards of dirt excavated	▪ 138,500 linear feet of woven-wire wildlife/large mammal fencing; additional fencing between Siphons 7 and 21 in 2008
▪ 385 million gallons of water for dust control	▪ 42 large mammal permanent watering ponds; 14 additional in 2008
▪ Approximately 260 acres of clearing and grubbing	▪ 3,000 large trees

The crowning achievement of the completed CCLP is an average annual conserved water savings of over 26,000 acre-feet. This conserved water, by an agreement between SDCWA and the Metropolitan Water District of Southern California, is conveyed through the Colorado River Aqueduct to the city of San Diego and the SLR Settlement Parties for urban use. Additionally, the CCLP advances the economic stability of the collective regions by meeting the goals of the water transfer requirements. During construction, it was imperative to continue water flowing in the canals so that the deliveries to the Coachella Valley agricultural community would not be interrupted. Unique construction of the parallel canal with tie-ins accomplished this requirement.

Economic Feasibility and Budget Performance

In 1998, SB 1765 authorized $235 million for implementing the QSA. Of this amount, $200 million was appropriated for the two canal lining projects: the CCLP and the All-American Canal Lining Project. Of this total, $83.65 million was provided for the CCLP. With a total CCLP cost of approximately $120 million, the SDCWA provided about $36 million toward the cost of the project. Total yield of conserved water from the CCLP is estimated at 30,850 acre-feet per year (afy). Of this total, 4,850 afy is allocated for environmental mitigation water; 21,500 afy to SDCWA; and 4,500 to the SLR Parties. The agreement provides that in any year of the 110-year term if mitigation water or any portion of it is not used, the balance of that water is to go to SDCWA. SDCWA has purchased and developed a parcel of land in the project area that generates groundwater that can also be used to supplement environmental mitigation water. Based on findings to date, it is estimated that 2,500 afy of groundwater will be produced and used for environmental mitigation. Based on this straightforward analysis, the cost to SDCWA per acre-foot of conserved water is highly competitive with other water supply opportunities. Further, the CCLP provides a long-term reliable water supply, particularly when the reliability of State Water Project water is in question, and contributes in meeting the SDCWA water supply diversification targets. The following factors were considered by SDCWA when accepting responsibility for the implementation of the CCLP and the benefits received from the additional water supply:

Supply Reliability. There is no other readily available water supply that possesses the priority level, comparative low cost, amount and the duration of water supply resulting from the canal lining projects; CCLP and AACLP.

Narrowing the Water Reliability Gap. The acquisition of additional water supply from the CCLP is consistent with SDCWA goals to enhance water supply diversification and reliability, creating less dependence on more costly, and sometimes unavailable, MWD imported water.

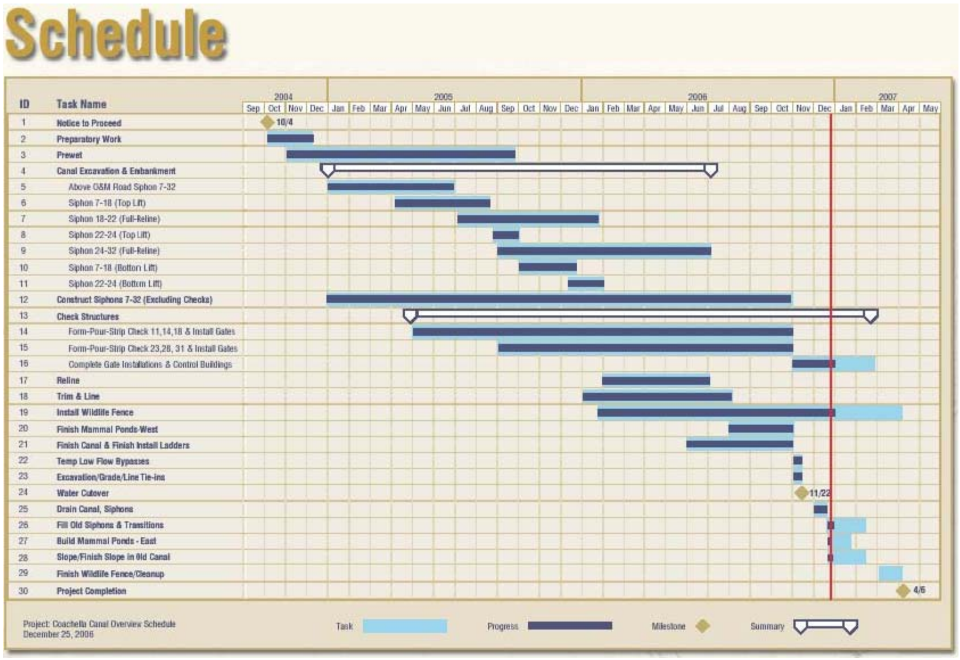
More Economical than Other Supply and Reliability Options. SDCWA is committed to increasing water reliability through a multifaceted approach, including infrastructure improvements, water transfers, and local development. Each of these measures comes with a cost. The CCLP was a cost-competitive opportunity to acquire at least 21,500 acre feet of additional firm water supplies for 110 years. The marginal cost of the CCLP compares favorably to other water transfers and supply options. Additionally, the supply risks have been shown to be significantly lower than other options.

Original Budget	$99.63 million
Revised Budget	$119.70 million
Over/Under Budget	$20.07 million
Contract Breakdown:	
Design	$2,500,000
Construction	$88,306,000
Construction Management	$3,950,000
Environmental Services/Permitting	$4,890,000
Environmental Mitigation/Land Acquisition	$12,046,410
Various Environmental Mitigation Contracts	$808,600
Agency Project Costs	$7,199,000
Sources of Funding:	
DWR (70%):	$83.65 million
SDCWA (30%):	$36.05 million
Approximate Capital Value	$88.3 million

Unprecedented State Funding for Water Supply Project. Through the QSA, the State of California provided $83.65 million toward a water supply capital improvement project. Never before have the project partners been presented with such a funding opportunity. Additionally, CVWD benefits from a new canal with modern technology and function, providing for efficient operations and maintenance. Additionally, CVWD will receive reimbursement by SDCWA for 110 years for the cost to operate and maintain the CCLP portion of the canal above the agreed 10-year average of costs for operations and maintenance prior to lining of the canal. Finally, as owner of the canal, the USBR receives 36.5 miles of new canal and a fully lined Coachella Canal, completing what began in the 1980s with lining of the first 49 miles. The QSA and the CCLP will have a profound and lasting effect on the San Diego and Coachella Valley regions for generations to come. The CCLP was constructed based on sound economic feasibility with the vision of the future and appreciation for the long-term beneficial impacts on future generations.

PROJECT SCHEDULE

Notice to Proceed:	October 4, 2004
Ribbon Cutting Ceremony:	November 2006
Project Completion:	April 2007
Notice of Completion Filed:	September 7, 2007 (with Riverside County)
	September 10, 2007 (with Imperial County)



PROJECT TEAM, MANAGEMENT STRUCTURE AND ADMINISTRATION

Project Owner

U.S. Department of the Interior, Bureau of Reclamation

Project Operation and Maintenance

Coachella Valley Water District

Project Partners

Coachella Valley Water District — Responsible for all contracting for services and overall management of the design and construction of the project.

San Diego County Water Authority — Responsible for eligible project costs beyond the DWR-funded amount. Provided essential project oversight and due diligence review of construction, property acquisition, and environmental mitigation activities.

US Bureau of Reclamation — Reclamation is the project owner and had a vested interest in partnering for the success of the project. Reclamation participated in review of project design and construction, provided additional QA/QC of project construction.

California Department of Water Resources — Contributed $83.65 million to fund the project.

Advisors

- California Department of Fish and Game (DFG)
- U.S. Bureau of Land Management (BLM)
- U.S. Fish and Wildlife Service (FWS)
- San Luis Rey Indian Parties (SLR Parties)

Project Designer/Construction Manager

MWH/GEI Consultants, Inc. team provided design, construction support and construction management services.

Environmental Coordination

Harvey Consulting Group, LLC coordinated the overall environmental effort for the project, and provided assistance with environmental permitting, development of conservation plans and environmental documents, including estimating mitigation costs for approximately seven different mitigation efforts.

AMEC Earth and Environmental, Inc. provided permitting assistance, mitigation measures identification, field survey, CEQA assistance, and general environmental services.

ASM Affiliates, Inc. provided services for the preparation of the cultural resources and historical context report.

Project Constructor

R & L Brosamer, Inc.

Special Consultant to San Diego County Water Authority

R.W. Beck, Inc. provided project management, engineering support and construction support through due diligence review of construction, property acquisition, and environmental mitigation activities.

Coordinating Committees

A key factor in the success of the CCLP was the strong coordination and collaboration among the project partners through the establishment of a Coordinating Committee and an Operations, Maintenance, and Repair (OM&R) Coordinating Committee. These committees were instrumental in moving the project forward on schedule in an organized approach.

Coordinating Committee. The Coordinating Committee was established by means of an agreement among the USBR, CVWD, and SDCWA. The Coordinating Committee serves to secure effective cooperation and interchange of information and provide consultations, reviews, recommendations, approvals on a prompt and orderly basis, and to make recommendations to the USBR.

The Coordinating Committee includes three voting members, one each appointed by CVWD and SDCWA, and the third member jointly appointed by the two agencies. Non-voting members include USBR, IID, Palo Verde Irrigation District (PVID), SLR Parties, and DWR. The SLR Parties and DWR also are advisory to provide viewpoints regarding specific matters. Reclamation is an advisory member for technical information to assist in making recommendations to USBR.

The Coordinating Committee met monthly to review and make recommendations on matters relating to the design and construction of the CCLP. This includes design and construction, documentation, schedules, water capacity in the Coachella Canal, and remedial measures for public health and safety. The Committee continues to meet bi-monthly to discuss and address ongoing work activities related to environmental mitigation.

Operations, Maintenance, and Repair (OM&R) Coordinating Committee. The OM&R Coordinating Committee, required by the Allocation Agreement, was formed to secure "prompt, orderly and effective cooperation and exchange of information and providing consultation, review, recommendation, and/or approval among the parties in connection with additional costs of operation, maintenance, and repairs of the…Coachella Canal."

Committee members include representatives from CVWD, SDCWA, IID, and SLR Parties. The Committee meets monthly to review operations and maintenance activities and scheduling, environmental activities, and overall project expenses, work elements, and invoice approval.

Environmental Groups

The CCLP environmental groups provide essential and technical knowledge on environmental issues of the project related to environmental mitigation. These groups are advisory to the Coordinating and OM&R Committees.

Biological Working Group. The Biological Working Group includes CVWD, SDCWA, USBR, DFG, FWS, BLM, and CNLM (Center for Natural Land Management). This group provides coordination with and technical environmental advice to of the CCLP mitigation effort as it affects land and habitat management activities within the larger Dos Palmas Area of Critical Concern.

Environmental Management Group. The Environmental Management Group includes representatives from each of the project partners. This group tracks and evaluates mitigation requirements and provides recommendations to the Coordinating Committees for initiating and funding mitigation efforts, including large mammal management, desert riparian re-vegetation restoration, marsh creation, and offsite fishery enhancement.

TEAMWORK IN DESIGN

The Preferred Alternative included in FEIS/EIR consisted of lining the existing canal using multiple pipe barrels and movable pumping stations to divert and convey the required 600 cfs to maintain canal deliveries. It was determined early in the design phase that the EIS-listed Preferred Alternative could not be constructed within the time and funding limits of the project. The estimated cost would be about $30 million above budget and as much as two years past the required completion date.

Developing an alternative concept for design of the CCLP was complicated due to a significant number of varied conditions that had to be met, along with funding and schedule constraints. The following summarizes these conditions.

- The project had to be completed without interruption to CVWD deliveries to its valley growers. A minimum 600 cfs capacity had to be available for these deliveries at all times.

- The CCLP traverses the base of the Chocolate Mountains. Rainfall runoff from the uphill watershed is trained to pass the canal in 25 washes that cross the canal within the project area. These washes can have relatively large, flashing, and unpredictable flows. If the existing canal were to be lined as originally planned, canal diversions to maintain the 600 cfs deliveries described above would cross and block the washes leaving a relatively high risk for interruption to irrigation deliveries if and when the washes flowed. This risk condition had to be considered in the design.

- Commitments made in the EIS/EIR, including:

    - In order to minimize environmental impacts, no additional rights of way would be acquired.

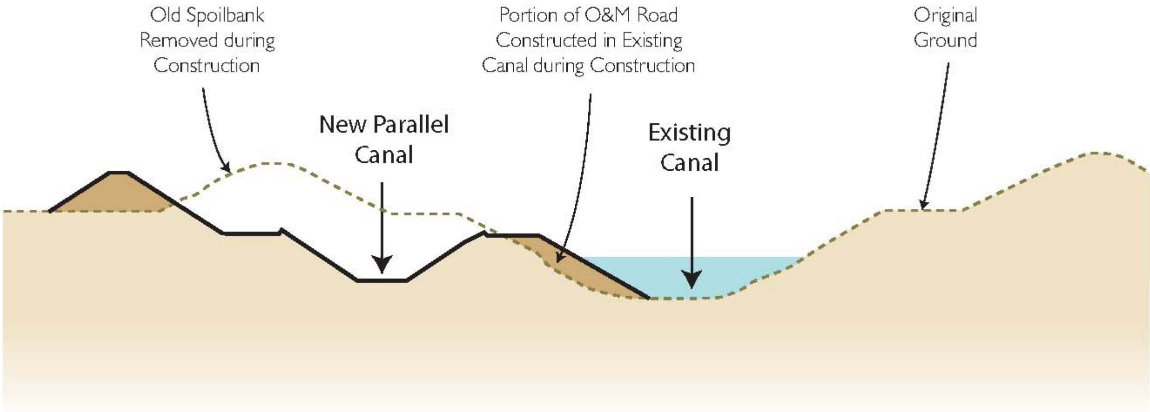
    - Provide features for large mammal escapes consisting of constructing canal ridges in the new canal side slopes.

- Concepts other than the Preferred Alternative could require amendment to the FEIS/EIR which might delay the project.

- A completion date was set to satisfy concerns of the other Colorado River Basin states that California was indeed working to meet its commitment to reduce its use of Colorado River water to the limits of its allocation.

- The DWR provided the majority of the funding (70%) for the project. The attempt to keep the project within the DWR funding limits was a significant driver in the design concepts and related decision making.

After much consideration and study, an alternative was developed for lining the existing canal by constructing a bypass canal for diversion of the 600 cfs canal deliveries. The Bypass Alternative essentially substituted a temporary canal for the pipeline and pump station concept included in the FEIS/EIR - Preferred Alternative. This alternative would fit within the funding available for the project and was developed to nearly 100 percent completion. It would involve constructing the bypass channel across the washes which at first was considered an acceptable risk for the project. However, as the design progressed, this risk of failure to maintain a reliable delivery capability to CVWD during and immediately after a desert rainfall event became more and more of a concern.



The selected alternative used excess excavation material to create a suffiently-wide O&M road by encroaching on the old canal, thus lowering hauling costs.

As the design of the Bypass Alternative was underway, a new parallel canal concept emerged that would become the only concept that would meet all of the constraints and criteria and ultimately be implemented into the project design. Based on preliminary estimates, the cost to construct an entirely new parallel canal including new siphons would be approximately the same as the estimated cost for the Bypass design. The existing double box siphons are over 60 years old. The concrete headwalls of a number of the siphon transition structures showed signs of deterioration. From inspection and testing of the concrete it was determined that the deterioration was from carbonation and on many structures the face of the concrete had actually split away from the reinforcing.

As it turned out, the decision to avoid risk at the wash crossings was an exceptional one. The year 2005 was a very wet hydrologic year with over 2.5 times the normal rainfall at the project site. The washes had very heavy flows a number of times. During construction of the CCLP, it was discovered in some areas along the alignment that this wet cycle had resulted in increased groundwater levels than what was originally found during the design phase.

Implementation of the new parallel canal concept required a number of innovative, perhaps unorthodox, design and construction elements. Also, as the design of the parallel canal was underway, additional boring logs were taken along the new centerline. High groundwater was discovered in the areas of Siphons 9, 10, and 18.

In order to design and construct a parallel canal within the existing right-of-way and meet all of the conditions set forth above, the following design elements were required:

- The new canal was designed to be exactly parallel and offset from the existing canal. In some areas there was not enough existing right-of-way to construct the new canal without constructing a portion of the O&M road in the existing canal while under operation.

- In order to reduce costs for hauling excess excavated material, the design allowed the contractor to deposit the material in the existing canal while under operation.

- To prevent transport of suspended sediment into the CVWD service area from the two above described operations, a rock weir was constructed at the downstream end of the existing canal to form a 10-mile-long sediment control pond.

- As the design progressed, an idea was developed to extend the project upstream into the end of the first 49 miles of lining that was completed in the 1980s by removing the Parshall flume that was part of the lining project. The Parshall flume operated with a four foot drop in water surface across the structure.

  By eliminating the flume, the invert of the new canal was raised four feet. This change resulted in a significant reduction in required excavation and a reduction in dewatering concerns. It also reduced the overall width of the new canal section for a better fit in the existing right-of-way.

  To replace the measurement function of the Parshall flume, a long-throated flume was constructed in the new canal. This type of flow measurement structure can function within acceptable accuracy with only 0.60 feet of differential head across the structure.

During design, the canal ridges required (for large mammal access and egress) in the original EIS were determined to be incompatible with canal lining without having a PVC liner beneath the concrete canal lining. Construction of the ridges would not be conducive to modern production lining operations, and the cost would be prohibitive. To meet the EIS obligation for large mammal protection, the EIS was amended to include wildlife fencing and ponds to provide access to water for deer and other large mammals.

TEAMWORK IN CONSTRUCTION

The construction contractor, R&L Brosamer, Inc., used a variety of innovative methods and equipment for completing construction of the CCLP. These methods and equipment are listed below.

- **Design/Fabrication of Traveling Forms:** The contractor designed and fabricated its own traveling forms for construction of the 1.6 miles of double 10.5’ x10.5’ box siphons for the project. The traveling forms used hydraulic cylinders that caused the top of the form and the sides to collapse and fold in during stripping. This made it possible to strip, move forward, and be in place for the next placement in a matter hours

- **"Dust Abator":** The contractor developed a piece of equipment that was coined the "Dust Abator" that consisted of large pump suspended from the boom of a rubber-tired mobile crane and fire nozzle to spray water over the work area for dust control.

- **Drain Tile and Sump System for Dewatering:** The contractor employed a drain tile and sump system for dewatering the canal. Their dewatering subcontractor used a specially designed trenching machine to insert the drain tile and pea gravel pack in the invert of the canal in the same operation. The work could be accomplished even with water in the invert of the canal.

- **Hitachi 1900 Excavator:** Due to the nature of the excavation for this project, a large portion of the work was accomplished with excavators. The contractor purchased a new Hitachi 1900 that was shipped from Japan for this work. The excavator had a 2000 cy/hr production rating.

- **High-Production Paving Train:** The contractor's canal lining paving train included a trimmer, paver, joint inserter, finishing jumbo, and curing jumbo, which reached production rates of nearly ½ mile per day. The joint inserters inserted PVC water stop at 12' centers longitudinally along the canal and transverse to the canal.

CONCLUSION

The Coachella Canal Lining Project (CCLP) is a substantial accomplishment in meeting a goal of the 2003 Quantification Settlement Agreement to conserve Colorado River water for beneficial use. The CCLP represents a significant and timely achievement in the history of the Coachella and Imperial Valleys, and the San Diego and Imperial Valley regions. The CCLP advances the economic stability and contributes to the well being of the regions by meeting the goals of the water transfer requirements by conserving 26,000 acre-feet per year of water to be transferred to San Diego County for urban use Notably, the CCLP overcame challenges of keeping water flowing in the canals during construction by innovatively designing and building a parallel canal adjacent to the old canal in the same 200 foot-wide right-of-way. The two canals, from centerline to centerline, are only 80 to100 feet apart.

THE ALL-AMERICAN CANAL LINING PROJECT: INTERAGENCY TEAMWORK FOR CONSERVING WATER

Paul Peschel[1]
Wayne Dahl[2]
Paul Snipes[3]
Neena Kuzmich[4]
Todd Shields[5]
Chris Dull[6]
Ken Steele[7]
Vikki Dee Bradshaw[8]

ABSTRACT

The All-American Canal Lining Project (AACLP) is one of the largest water conservation efforts in the United States saving 67,700 acre-feet of Colorado River water per year. This conserved water assists California in remaining within its Compact allocation of Colorado River Water without jeopardizing its agricultural or urban economies. It also contributes to the settlement of a long-standing San Luis Rey River water rights dispute in Southern California. Total project costs are projected to be over $300 million including design, construction, environmental mitigation, supervision, administration and litigation costs.

The United States Bureau of Reclamation (Reclamation) completed construction of the unlined All-American Canal (AAC) in 1942. This 83-mile-long canal is operated and maintained by the Imperial Irrigation District (IID). As the largest irrigation district in the United States, with a total service territory encompassing nearly 1.1 million acres, IID supplies approximately 3.1 MAF of water per year to over 500,000 acres of highly productive agriculture farmland and nine communities. IID is the lead agency for the AACLP being responsible for project management, design, construction, and environmental compliance. Project funding is provided by the California Department of Water Resources (DWR) and the San Diego County Water Authority (SDCWA). As a result of this conservation, SDCWA will receive 56,200 acre-feet per year and the San Luis Rey Settlement Parties (SLRSP) 11,500 acre-feet. A Project Coordinating Committee (PCC) was established to provide project oversight, facilitate project decision making and provide a mechanism for structured communication among the participating entities and interested parties.

---

1 Chief Engineer, IID, PO Box 937, Imperial , CA 92251: pgpeschel@iid.com

2 President, Dahl Consultants, Inc., 157 Parkshore Drive, Folsom, CA 95630; wdahl@dahlconsultants.com

3 Construction Manager, Parsons Water and Infrastructure Group, Inc., PO Box 55 Winterhaven, CA 92251; paul.snipes@parsons.com

4 Project Manager, R W Beck, 15373 Innovation Drive, Suite 390, San Diego, CA 92128; nkuzmich@rwbeck.com

5 Executive Program Manager, IID, PO Box 937, Imperial, CA 92251; toddshields@iid.com

6 Vice President, R W Beck, 15373 Innovation Drive, Suite 390, San Diego, CA 92128; cdull@rwbeck.com

7 Consultant, 1740 Burnside Way, Stockton, CA 95207; kensteele@sbcglobal.net

8 AACLP Designated Biologist, IID, PO Box 937, Imperial , CA 92251: vdbradshaw@iid.com

HISTORICAL PERSPECTIVE

Authorized and constructed pursuant to the Boulder Canyon Project Act, construction of the 83-mile long All-American Canal (AAC) began in 1934 with the first irrigation water being delivered in 1940. The AAC is operated and maintained by the Imperial Irrigation District (IID) under contract with the United States Bureau of Reclamation (Reclamation). A 23-mile-long segment of the canal, delineated in Figure 1, was excavated primarily in sand which resulted in relatively high seepage rates through this section of the canal. Because of this high water loss, this segment was selected for lining and formed the basis of the project.

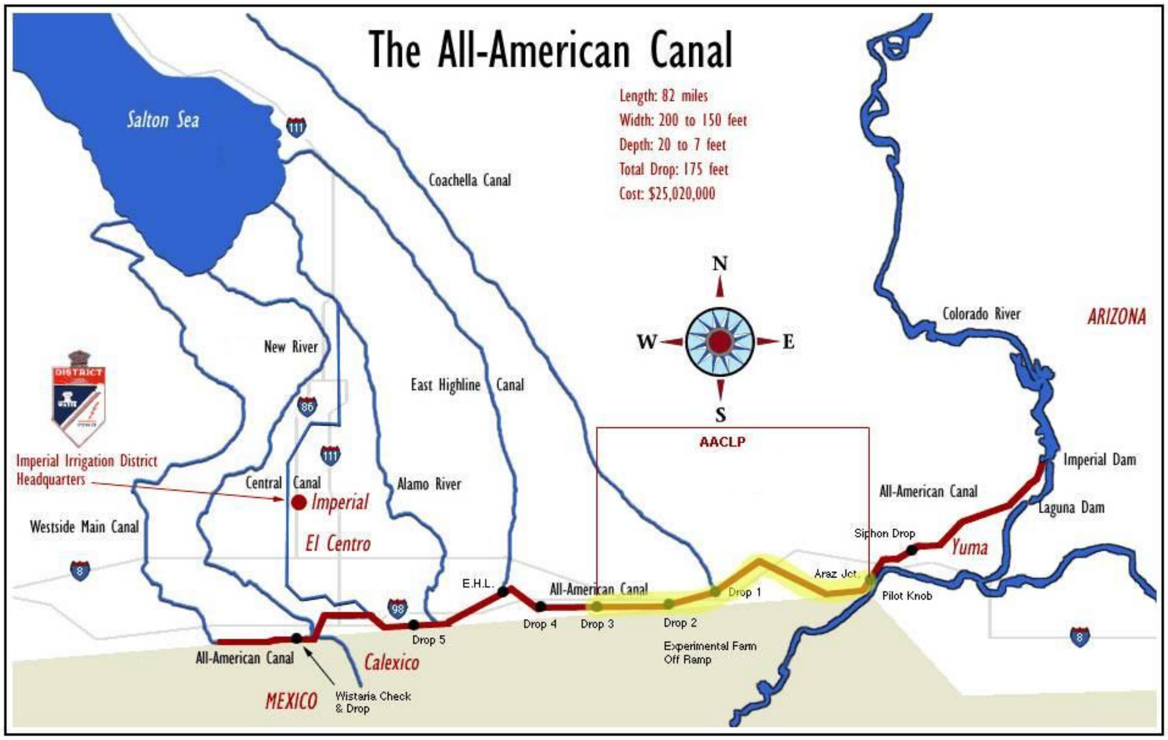


Figure 1. All American Canal Lining Project

The concept of lining the AAC was studied many times over the past 30 years as this project was seen as a means to help California live within its 4.4 million acre-foot Colorado River allocation. As such, the current project was originally conceived and later developed by, IID and the Metropolitan Water District of Southern California (MWDSC) in coordination with Reclamation. Planning studies were completed in the 1990's and Federal and California environmental documents were certified on June 28, 2002. The State of California (California) provided funding for the project based on project scope and cost estimates provided by MWDSC and Reclamation. MWDSC would be required to provide funds to complete the project if State funds were insufficient. As such, this project is included as a strategic element of the Quantification Settlement Agreement (QSA) which codifies California's larger water conservation and water use reduction efforts aimed at reducing the State's overall Colorado River water use to within the its allocation limit. This larger effort in part involves the implementation of water conservation measures and the facilitation of water transfers which are elements of California's unified approach to resolve water use issues. This unified approach facilitated an end to legal actions among water and government agencies. In 2003, to help facilitate communication among various water agencies and help ensure California's larger conservation goals were met with regard to Colorado River use, San Diego County Water Authority (SDCWA) assumed MWDSC's All-American Canal Lining Project (AACLP) responsibilities. Concurrently, MWDSC's program manager joined IID to manage the AACLP.

PROJECT DESCRIPTION

The project consists of three distinct reaches, as shown in Figure 2. Reach 1 begins approximately one mile west of Pilot Knob and continues westerly approximately 11 miles to the Coachella Canal and Drop 1 Power Plant confluence. Reach 2 begins at Drop 1 and continues westerly approximately 5 miles to the Drop 2 Power Plant. Reach 3 continues from the Drop 2 Power Plant, approximately 5 miles to the Drop 3 Power Plant.

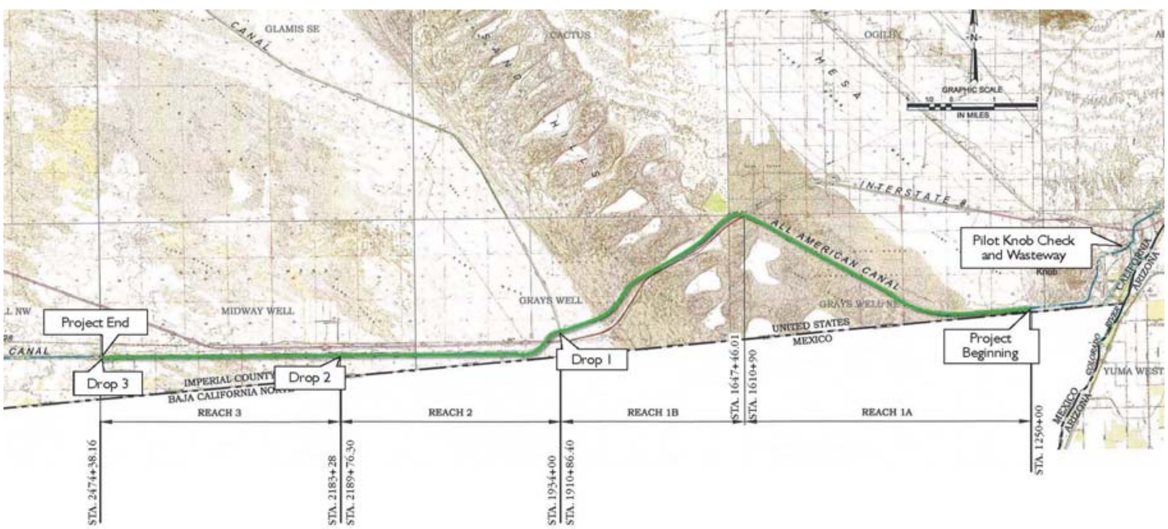


Figure 2. All American Canal Lining Project Reaches

The AACLP consists of a new, concrete-lined canal constructed primarily parallel to 23 miles of the existing AAC. One element of the project, which is intended to mitigate lost storage volume and operational impacts resulting from the reduced cross-section, includes a 5-mile-long, 1,250-acre-foot, PVC-lined, off-line storage (OLS) reservoir. The new canal connects to the existing canal at nine locations, enabling the new system to continue the use of three drop structures with hydroelectric power and two interstate highway bridges.

Construction involved excavating 22.5 million cubic yards of primarily sandy material, placing 1,910,000 square yards of 4.25-inch-thick, concrete paving, and installing 600,000 square yards of PVC liner in the OLS. Some of the appurtenant features included a two-lane bridge, flow measurement flume, gates, 96-inch diameter reinforced concrete pipe (RCP) and a supervisory control and data acquisition (SCADA) system.

The total project cost is projected to be over $300 million of which $170.39 million is provided by California Department of Water Resources (DWR). Total project costs include design, construction, environmental mitigation, supervision, administration and costs associated with litigation.

PROJECT SCHEDULE

Four factors helped drive the establishment of a project completion date: the need for water and for California to comply with its Colorado River allocation, the requirement for agricultural agencies to begin repayment of inadvertent overuse of Colorado River water, the need to complete the project prior to expiration of State funding and the projected duration of work. The design firm was selected in September of 2004 with design beginning in October of that same year. Bid documents were first posted on California's bidding website on February 1, 2006 and bids were received in late March 2006 (Reaches 2 and 3) and mid-April 2006 (Reach 1). Notice to proceed with construction was issued by IID on July 26, 2006. An injunction prohibiting work on the project was issued by United States 9th Circuit Court of Appeals on August 24, 2006, and construction ceased on August 25, 2006. The injunction was lifted on April 6, 2007 with work resuming shortly thereafter. The newly lined canal was in full operation in February 2009 with the exception of a few remaining concrete tie-ins to the existing canal. These tie-ins are projected to be completed in February of 2010. Site clean-up and restoration will be completed by March 30, 2010. Some environmental mitigation activities will continue after construction. All project milestones were met.

PROJECT TEAM, MANAGEMENT STRUCTURE AND ADMINISTRATION

The project team included the Executive Program Director and IID staff, Reclamation, Parson's program and construction management (PM/CM) team, the GEI/MWH design team, Reach 2 an 3 construction contractor Ames/Coffman Joint Venture, Reach 1 contractor Kiewit Pacific Company, environmental consultants EcoSystems Restoration and Associates and RECON, cultural resources consultant ASM, and staff and engineering consultant RW Beck from SDCWA.

Four significant interagency agreements governed execution of the AACLP. In accordance with these agreements, IID's procurement, financial and administrative processes were used for all project elements, except that SDCWA's processes were used for any consultants retained by their agency. IID operates and maintains the AAC under agreement with the Reclamation and will continue this responsibility after completion of the AACLP. SDCWA will be responsible for additional operation and maintenance costs resulting from the AACLP through the term of the agreement with IID.

A key component of the project team was the Project Coordinating Committee (Committee), which was established by Construction Agreement among Reclamation, IID and SDCWA. The Committee's mission was:

- To secure effective cooperation and interchange of information.
- To provide consultations, reviews, recommendations, and approvals on a prompt and orderly basis among the members/participants in connection with project activities.
- To make recommendations, including project acceptance to Reclamation, the federal agency that holds title to the AAC, for their approval regarding the design and construction of the project.
- To approve contracts awarded by IID and related contract actions.
- To approve the project schedule and validate eligible project costs.

The Committee consists of three voting members; one from the IID, one from the SDCWA, and an independent member selected by the IID and SDCWA. The independent member was the chairman and presided over Committee meetings which were held monthly. Other organizations participated in Committee meetings as non-voting members. These included:

- Reclamation;
- Coachella Valley Water District (CVWD);
- Palo Verde Irrigation District (PVID);
- San Luis Rey Indian Water Rights Settlement Parties, (Five bands of Mission Indians, the San Luis Rey Indian Water Authority, the City of Escondido, and Vista Irrigation District who will receive a total of 11,500 AF per year of the water conserved by the AACLP.);
- DWR; and
- Other invited participants such as U.S. Bureau of Land Management (BLM), Border Patrol of the U.S. Department of Homeland Security (DHS) and California Department of Fish and Game (DFG).

One role of the Committee is its leadership function. The Committee provided guidance and direction to the Executive Program Manager and project management consultant at Committee meetings regarding high level administrative and cost issues during project construction. As such, the construction contractors did not participate in regular Committee meetings. However, the Committee voting members participated in executive level partnering sessions with the construction contractors and in negotiations and discussions regarding potential construction disputes.

TEAMWORK IN DESIGN

To expedite the project, certain design elements were interfaced with construction management services. As such, the first consulting contract established for the AACLP was the PM/CM contract. This contract provided key services, such as air quality impact analyses, geotechnical and groundwater investigations, recreation and transportation planning to support the design and construction phases of the project. A “fast track” design contract was awarded in late 2004 and completed in about one year.

To further expedite the design process, the design engineer prepared 13 design concept papers to establish standards for project elements and assure compliance with Reclamation standards and conformity with project scope and environmental requirements. These papers provided the basis for development of the Concept Design Report. The Design Concepts Report was reviewed by Reclamation, the PM/CM, IID staff, and SDCWA staff and representatives. Design workshops were conducted to help resolve issues and address comments pertaining to the various design concepts. The Concept Design Report was then used as the foundation for the expedited design.

An important element of design review process was the use of day-long workshops involving the entire project team. These workshops provided a forum for the owner and other project participants to work together and provide critical feedback and “real-time” review. The use of this technique helped the design team complete the project design in a relatively short time period.

As a direct result of the design review process, during the pre-design and design phases, numerous innovative and cost-saving ideas were developed and integrated into the final design package. Project cost and schedule savings initiatives included an alignment revision to avoid excavation in the most expansive area of sand dunes, optimization of canal side slopes, and canal section modifications to optimize paving operations.

TEAMWORK IN CONSTRUCTION

With the start of construction, project field oversight activities were required. The PM/CM thus established a consolidated field office near the on-site contractor field offices which also housed representatives of the design firm, Reclamation and SDCWA.

To better address construction phase challenges, the project owner’s team established quarterly partnering and weekly progress meetings with the contractors. Quarterly partnering meetings, facilitated by a third party, permitted candid and timely exchanges regarding concerns and issues. Furthermore, weekly coordination meetings were held in the contractor’s field offices allowing for timely and thorough discussion of pertinent issues and items. These meetings were attended by all key construction personnel, consultants and off-site team members. This teamwork approach allowed for the timely identification of issues which resulted in proactive solutions thus avoiding problems.

As further evidence of the team's commitment to an effective and economical conservation project, an aggressive safety program was established to meet both Reclamation and IID standards. This upfront planning approach paid big dividends as lost accidents were limited to one rather small event for the entire project. Over 22.5 million cubic yards of sand was excavated parallel to, and in close proximity to, Interstate 8 without incident.

Before excavation was permitted, the contractor was required to pre-wet the soil volume corresponding to the canal section to be excavated and provide verification that the sand met the specified moisture content 8-feet below the bottom of the excavation (sometimes as deep as 45 feet below the existing surface). Interstate motorist traveling both east and west and recreational "duners" could observe the large sprinkler systems spraying water over the sand dunes. Water trucks were constantly ensuring construction access roads were dust free.

CHALLENGES AND OPPORTUNITIES

Project Scope and Cost

During the course of finalizing the Construction Agreement, it became apparent that; project costs might significantly exceed DWR's funding authorization even without litigation and delays; elements of the project scope as determined by cost estimates and other project planning documents needed to be clarified; that for the Committee to function as envisioned the contracting authorities for the project would need to be synchronized with the contracting authorities of both IID and SDCWA. Executives from Reclamation, IID and SDCWA accomplished this with provisions contained in the construction agreement. Some examples of these provisions are:

1. The requirement for a unanimous vote of the Committee to approve the project's construction management manual. This would align contract modification authorities of the Committee with IID's Executive Program Manager, the PM/CM and those of the SDCWA.
2. Define the location and size of the off-line regulating storage reservoir and a variation in canal side slopes.
3. Provide an opportunity for SDCWA to omit Reach 3 of the project and IID to seek other funding sponsors for this project element if the projected cost of the project, as determined following bid opening, exceeded DWR funding.

Lawsuit-Related Construction Delays

In August 2006, following award and issuance on notices to proceed for the two construction elements, the United States 9th Circuit Court of Appeals issued an injunction halting work on the project. Executives and legal counsels for Reclamation, IID and SDCWA allied to fight the litigation against the project and eventually prevailed.

Because project partners anticipated project delays associated with potential lawsuits, a 60-day suspension clause was included in the contract documents. Nonetheless, it became clear shortly after the injunction that the 60-day contract provision would not be sufficient. As such the project team began termination negotiations with the contractors. As the litigation progressed it became apparent that the duration of the delay could be up to two years with the need to coordinate certain construction activities during low flow periods in the canal. At that point the project team approached the construction contractors about negotiating an extended delay as well as possible termination.

Following the initial discussion with the contractors, the PM/CM, with IID and SDCWA participation, negotiated a contract modification with both contractors. This effort resulted in a contract modification that provided a delay payment to the contractors and allowed the project to proceed with the original contractor after a one year delay if a decision to move forward was made by April 2007. The contract modifications also outlined termination costs for various time periods in the event that a decision to terminate was necessary prior to that date.

In December 2006, Congress passed legislation declaring that the project was in compliance with Federal environmental laws. As such the courts ruled in favor of the project with regard to water rights and other matters allowing the project to resume prior to the required termination notification date.

Severe Construction Conditions and Non-Interruptible Canal Flows

As described above, the project's complexity was magnified by the legal challenges. Even without the legal challenge, the combination of harsh desert working conditions, no impacts on water deliveries during construction, and the relatively remote location and its proximity to the border with Mexico alone would have made AACLP a challenging project. Temperatures exceeding 120 degrees were addressed with night placement of concrete, on-site production plants, chillers, and the use of high strength concrete. As a result of these efforts, water deliveries were never interrupted. Start-up planning and meetings with operations, construction contractors and construction management allowed for coordinated net changes in water flows. This was accomplished in part by diverting flows into new facilities while terminating water flows in reaches of the original earthen canal.

Recreational Use of the Area

One interesting aspect of the project was the need to accommodate, during winter months, the annual massive influx of recreationists. Several hundred thousand snowbirds and dune buggy enthusiasts (duners) descend on the area from late fall through spring. To ensure continued use of the area, for recreation, while allowing for construction of the AACLP, the project team and Federal, State and County agencies prepared a detailed transportation and recreation plan for the protection of visitors and construction personnel. The plan featured extensive signage and an aggressive public outreach program and provided construction progress updates. This information was available on the project's web page. A total of four newsletters were produced and distributed at various recreational trade shows and events and at four kiosks located throughout the recreational area. The program proved to be very successful in minimizing construction and public access conflicts in heavy recreation use areas, many of which were adjacent to active construction zones. As a result of these efforts there were no recreational accidents linked to construction activities.

Environmental Compliance

The responsibility of the AACLP team was to successfully construct the canal while protecting the environment and natural resources in accordance with Federal and State laws and associated project permit requirements. To help ensure compliance with these requirements, an Environmental Training Handbook and a Worker's Environmental Education Program (WEEP) Video were developed. All persons involved with the AACLP were required to be WEEP-trained and were issued hard hats with decals indicating that required environmental training had been received. This was also sufficient for DHS security requirements.

Protecting special status wildlife was one of the most important responsibilities faced during AACLP construction. Special-status animals potentially in or near the project included: the Yuma Clapper Rail and 17 other bird species; the Flat-tailed Horned Lizard and two other reptiles; and the razorback sucker fish. Special-status plants located in the project area included: Algodones dunes sunflower and Peirson's milk-vetch. Several species of doves, all of which are protected under the Migratory Bird Treaty Act, reside within the study area.

Environmental mitigation includes 43 acres of wetland habitat and one acre of open water marsh, 30 acres of dune restoration, fish salvage operations, mitigation for the loss of canal fisheries, compliance with Cultural Treatment Plan, which included negotiations with the local Tribes, and the acquisition of 1,025 acres of flat-tailed horned lizard habitat. Actions taken to avoid and/or mitigate environmental impacts included conducting a detailed survey for bird nests during the Migratory Bird Treaty Act nesting Season and prior to construction grubbing of vegetation. All active nests that were found were protected with buffer zones until nesting was completed and the nestlings fledged. After the nestlings fledged the area was cleared for construction.

Air Quality Analysis and Permitting

In the fall of 2007, it seemed that the AACLP might fall victim to what appeared to be evolving interpretations of construction air quality permitting requirements. The situation may have been exacerbated by the actions of one of the contractors, who sought to defend his interpretation of statewide permits. Permit violation notices were issued to both contractors which delayed certain aspects of the project. Imperial County threatened legal action to ensure that the IID would resolve their concerns. During this process it appeared likely that construction would be delayed with yet another injunction. As a proactive approach to keep the project on its current schedule, the project team agreed that the most prudent course of action was to oppose the legal action by Imperial County or seek a combined settlement with the regulatory agencies. This agreement was with the understanding that there may be later disputes among project participants regarding violation responsibilities. As such, legal counsels for IID, SDCWA and the two construction contractors joined forces. As a result of this approach a settlement was reached with the local air quality management district. The project proceeded while good faith settlement negotiations took place. Following the settlement the contractors and the project team negotiated payment of settlement costs among the parties.

Sediment in the Canal

In the fall of 2008, large quantities of sediment were found in Reach 1 of the canal. The source and cause of the sediment was a matter of dispute between the owner's team and the Reach 1 contractor. Although a disputed item, there was recognition of the potential severe impact to canal operations and associated maintenance if a protective solution was not taken by the project team. If a project solution could not be devised, the potential consequences ranged from extensive silt removal maintenance in expansive reaches of IID's canal system if large quantities of the sediment washed downstream to potential crop and economic damages to the community if silt accumulation caused obstructions/interruptions of water delivery during the high demand periods.

The resulting proactive and coordinated response by the project team involved realignment of portions of the canal, revised crossover and canal tie-in schemes, revised paving techniques (this design modification increased the paving machine's utilization by allowing for its use within the canal transitions and a reduced remobilization for continued paving), some acceptance of accelerated cure techniques for some joint sealants, and expedited inspections of completed reworked paving by the PM/CM and Reclamation.

The result of this effort was the successful transfer of flows to the new lined canal prior to the onset of the high flow season. A side benefit was the availability of conserved water for about half of Reach 1 several months earlier than originally scheduled.

Coordination with Other Projects and Activities

Close coordination of construction activities was required with DHS because the project is parallel to the Mexican border. Soon after the injunction was lifted the IID requested that the AACLP Committee review DHS plans to install additional steel barriers. This included the addition of a pipe gate on the canal's south O&M road and at the AAC crossings under Interstate 8. As a result of this recommendation, DHS agreed to remove the new pipe gate during AACLP construction and to re-install the gate once construction was completed. This requirement was incorporated into the IID Encroachment Permit subsequently issued to DHS for this work.

Although not planned for during the Design Phase, DHS constructed a new Primary Border Fence along the U.S./Mexican Border from east of Sidewinder Road to west of Drop 3 while AACLP construction was under way in the same area. Once again the IID requested that the AACLP Committee review DHS plans pertaining to this construction effort. AACLP project team leads hosted a coordination meetings with the DHS contractor (Granite construction), AC Joint Venture and Kiewit Pacific to develop schedules allowing the DHS project and AACLP construction to proceed simultaneously without impacting either project. This coordinated effort resulted in the successful completion of the border fence during construction of the AACLP without incidents to either construction project. Completion of the border fence eliminated high speed chases incidents involving drug runners crossing the border through the AACLP construction site. DHS periodically provided AACLP project representatives with aerial photographs of the construction site as a cooperative effort to help maintain project safety and security.

Another opportunity to facilitate conservation of Colorado River water arose with the approval of the Drop 2 Reservoir Project. This is a separate project funded by others who will receive its benefits. However, because it connects to the AAC in the Reach 3 of the AACLP opportunities for cost savings arose. As such, agreements were coordinated among IID, SDCWA, Reclamation and the funding agencies to allow IID's Reach 2/3 contractor to construct the reservoir element that would connect to the AACLP (prior to turning water into the newly lined canal section). This coordinated effort resulted in lower costs for the Drop 2 Reservoir Project, fewer impacts to canal operations and the newly constructed concrete lined canal, and no cost impacts to the AACLP project.

Loss of Key Project Leaders

Within about a six-month period of 2006, four senior leaders of the project passed away. They were: Kirk Dimmitt, Executive Program Manager first representing MWDSC then IID ; Joe Summers, Chairman of the Committee; Clyde Romney, long time supporter and SLRSP representative; and James "Pat" Green Reclamation's Environmental Manager for the project. While their passing represented a significant loss of both project institutional knowledge and leadership, their service to the project set the tone of teamwork and dedication that led to the project's successful completion.

CONCLUSION

The AACLP was officially dedicated on April 30, 2009. The dedication ceremony focused on and was a testament to what can be accomplished when agencies work together with a goal of conserving water for today and tomorrow.

FRESNO IRRIGATION DISTRICT'S THREE-YEAR MAINTENANCE AND FACILITY UPGRADE PLAN

Bill Stretch, PE[1]
David Mowry, PE[2]

ABSTRACT

The Fresno Irrigation District (District) is in its third and final year of an ambitious Three-Year Maintenance and Facility Upgrade Plan (Three-Year MFUP). The improvement costs are estimated at $18.5 million, with $10.3 million coming from bonds and $8.2 million coming from outside contributions. These outside contributions include federal and state grants and in-kind District labor. In order to minimize immediate fiscal impacts to landowners, the District decided to bond the initial capital funds and to repay them over time.

The Three-Year MFUP is structured in such a way that it "catches-up" on major infrastructure deficiencies and needs within the District, focusing on deferred maintenance projects and capital improvements. The capital improvements included retrofitting existing weir structures with long crested weirs and automated gates; SCADA and telemetry improvements; improved measurement at lateral headings and selected grower turnouts; regulation and recharge basins; replacement of leaking pipelines; lining problematic portions of open canals; automated trash racks; and improving rights-of-way along open canals. The projects are being constructed by contractors as well as the District's construction forces. Due to the specialized nature of the majority of the capital improvements the District has been able to minimize costs and construct a greater number of projects by utilizing its construction forces.

INTRODUCTION

The District, and its property owners, approved a supplemental assessment through a Proposition 218 election in December 2005. This was approved after 11 years of no property assessment increase. The majority of District revenues come from property assessments, representing approximately 71 percent of its total budget. The District's costs are currently allocated to landowners and/or water users through assessments and/or volumetric charges via eight (8) rate services. These eight rate structures represent varying degrees of water service, water supplies, benefits, agreements and legal settlements.

Property assessments had remained fixed since 1994 as a result of Proposition 218 (1996), which limited the District's ability to increase assessments. The supplemental assessment will help fund repayment obligations for bonds required to complete Three-

[1] Chief Engineer, Fresno Irrigation District, 2907 S. Maple Ave. Fresno, CA 93725 bstretch@fresnoirrigation.com
[2] Principal, Blair Church & Flynn Consulting Engineers, 451 Clovis Ave. Suite 200, Clovis, CA 93612 dmowry@bcf-engr.com.

Year MFUP portions of the District's Operations and Maintenance budget, new water right and irrigation-related regulatory fees implemented by the State of California, as well as the annual indexing of supplemental assessment components. Bond or loan obligations will be at actual annual cost and adjusted to the Consumer Price Index (CPI) to account for inflation.

The District plans on constructing $18.5 million of improvements, with $10.3 million coming from bonds and $8.2 million coming from outside contributions including federal and state grants, local agencies, and utilizing District construction labor and equipment by May 2010.

In order to minimize immediate fiscal impacts to the landowners, the District decided to bond the initial capital funds and repay them over time. Listed below is a table showing the eight project categories and their associated estimated costs for the Three-Year MFUP.

Table 1. Project Categories and Estimated Costs for the Three-Year MFUP

No.	Structure Type	Total Budget	Contributions by Others	Contributions by FID (Labor & Equipment)	Total Bonding
1	Pipelines	1,279,500	327,500	61,000	891,000
2	Lining and Rodent Barrier	797,702	-	209,595	588,107
3	Regulating Structures and Devices	1,380,914	-	359,000	1,021,914
4	Measuring Structures and Devices	4,445,294	5,000	1,724,275	2,716,019
5	Basins	3,629,709	250,000	199,500	3,180,209
6	Trashrakes	450,000	-	100,000	350,000
7	Misc. Canal Structures	2,580,550	1,066,854	177,575	1,336,121
8	Right of Way Levees and Encroachments	3,918,630	2,993,000	694,000	231,630
	System Construction	**18,482,299**	**4,642,354**	**3,524,945**	**10,315,000**

DISTRICT BACKGROUND

The District is located in California's San Joaquin Valley and provides service to approximately 245,000 acres. The District is located in the geographic center of Fresno County and its boundary extends from the San Joaquin River to the north, City of Easton to the south, the Kings River and Friant-Kern Canal to the east and just past the City of Kerman to the west.

Water is delivered to approximately 190,000 acres including the metropolitan areas of Fresno and Clovis. The agricultural lands within the District are predominately permanent crops (about 68 percent). The predominant agricultural crop in the District has been and continues to be grapes, however almonds and citrus have increased over the past 10 years. The conversion of agricultural lands to urban uses in the expanding Fresno-Clovis metropolitan area has significantly increased in recent years. Currently, about 150,000 acres (or 60 percent) of the District remains as farmed agricultural land, while approximate 30 percent is urban and 10 percent is rural residential.

The District was formed in 1920 as a successor to the privately owned Fresno Canal and Irrigation Company (Company). The District purchased all of the rights and property of the Company for the sum of $1,750,000. The assets of the company consisted of over 600 miles of canals and distribution works, which were constructed between the years 1860 and 1900, as well as extensive water rights on the Kings River. The District currently owns and operates approximately 676 miles of canals with approximately 355 miles being pipelined and 321 being open channel. The District operates and maintains approximately 40 regulating and recharge reservoirs spread across 750 acres, with 4,200 acre-feet of holding capacity. Of the total 750 acres, approximately 220 acres are utilized as a Ground Water Banking Facility which was developed several years ago as a joint project with the City of Clovis. The District also has an additional 2,200 acres of floodrights.

The District diverts an average of 500,000 acre-feet of surface water annually. The primary water supply for the District comes from its Kings River rights administered by the Kings River Water Association. The U.S. Army Corps of Engineers constructed the Pine Flat Dam in 1954, which has a capacity of 1,000,000 acre-feet. Of this, the District is entitled to approximately 26% of the average Kings River runoff. The District also has a small water supply off the San Joaquin River, with a Class II contract for 75,000 acre-feet through the Friant Division of the Central Valley Project (CVP). In addition, the District delivers 60,000 acre-feet of the City of Fresno’s Class I contract.

TYPES OF PROJECTS

The Three-Year MFUP was structured to alleviate major deficiencies and needs within the District, focusing on deferred maintenance projects and capital improvements. The capital improvements included retrofitting existing weir structures with long crested weirs and automated gates; Supervisory Control and Data Acquisition (SCADA) and telemetry improvements; improved measurement at lateral headings and selected grower turnouts; regulation and recharge basins; replacement of leaking pipelines; lining problematic portions of open canals; automated trash racks; and improving rights of way along open canals.

The projects listed in the Three-Year MFUP were identified as priorities by the Water Operations and Engineering Departments. The Three-Year MFUP was structured with the following main objectives:

- Address major deficiencies and needs within the District, focusing on deferred maintenance projects and capital improvements.
- Improve landowners' ability to better manage the surface water supply, which will be accomplished by upgrading a portion of the existing turnout gates.
- Implement the Mill-Herndon Canal "Superhighway".

Prioritization of Projects

The District has compiled a lengthy list of master planned projects over the past 15 years, but did not have the necessary funds to construct most of them. The master list included 160 projects which were prioritized by three different criteria: 1) Project Type (e.g. pipelines, lining and rodent barrier, regulating structures and devices, etc.), 2) Priority Number, and 3) Year Constructed. Prior to Proposition 218, the District created a detailed list of projects, with a short summary of each project and a three-year project schedule. The project summaries included a short description, project location and any financial considerations. Project costs were difficult to estimate because a majority of the projects were in very preliminary stages of design and an Engineer's estimate had not been completed. For example, there were numerous check structures identified to be retrofitted, but it was not known if an automated gate valve would be installed or if it would be retrofitted with a less expensive device such as a Irrigation Training and Research Center (ITRC) Flap Gate. The District developed criteria to prioritize the projects below:

1. Efficiency Improvement Projects: Projects that either increase efficiency in operations or decrease maintenance costs.
    a. *Non-Deferrable Capital Improvement Projects* - Projects that are essential for the continued operation of the canal system. By failing to complete this work, the ability of the District to continue to deliver water at the specified location is in question including:
        - *Maintenance/Operational Improvements (High Concern)* –Issues that cause a canal to be shut down several times per year and/or poor regulation exists, especially in areas which (may) no longer have operational spills. Problem can be addressed with canal lining, rodent barrier, level control gates, retrofitting existing weirs (long crested weirs), pipeline replacement, new or improved regulation basins, lift pumps, telemetry/automation, etc.
        - *Implement the Mill-Herndon Canal "Superhighway"* - Convert existing check structures that could pass changes in flow quickly from one end to the other, while maintaining a fairly constant upstream water level. The Mill-Herndon Canal are large mainlines that accept a wide range of fluctuations and operational canal spills. This will be accomplished by retrofitting existing weirs (long-crested weirs & Langemann Gates).

b. *Maintenance/Operational Improvements (Medium High Concern*) – Issues that cause a canal to be shut down an average of once per year and also where improved regulation is needed. Problem can be addressed with canal lining, rodent barrier, level control gates, retrofitting existing weirs (long crested weirs), pipeline replacement, regulation basins, lift pumps, telemetry/automation, etc.
c. *Turnout Measurement Improvements* - Improve the ability to equitably deliver water to those landowners relying principally upon surface water. Problem can be addressed with retrofitting the existing meter gate, installing an orifice plate or a flow meter.
d. *Improve Measurement on Mainlines and Spills* – Improvements will help operations, improve service and limit water leaving the District. Problem can be addressed with Replogle flumes, flow meters, Cipolletti weirs, etc.
e. *Improve Existing Basins and Measurement on Smaller Laterals* – Improvements will help operations, improve service and limit water leaving the District. Problem can be addressed with pipelines, lift pumps, long crested weirs, telemetry/automation, Replogle flumes, flow meters, Cipolletti weirs, etc.
f. *Preventive Maintenance* – Improve sections of canal where access is lacking, and where repairs are routinely made, but service has not yet been impacted. Problem can be addressed with clearing of rights-of-way (brushing and earthwork), long crested weirs (sediment), lining, rodent barriers, pipeline replacement, etc.

2. <u>Regulatory & Contractual Requirements:</u> Regulatory projects to ensure that facilities are in compliance with all applicable regulations and contractual agreements. Consists of projects with local agencies and improvements to facilities that have mutual benefits.

3. <u>Landowner, Developer or Agency Participation:</u> Projects requested by a landowner, developer or local agency wanting to improve a District facility for their own benefit. (If a canal is in poor condition and requires a large amount of maintenance it will be listed under a higher priority.) Participation shall be approved by the District's Board of Directors (BOD) on a case by case basis per Board Policy 102 and 102.1.
   a. *Adding Water Service* – Projects that will add revenue and improve groundwater conditions by installing a pipeline or constructing a canal. The BOD will decide if the new facility will be maintained by the District or the landowner.
   b. *Improving Facility* – Landowner requests to improve facility for his own benefit. The facility is in generally good condition.

Although the District developed a good master plan, staff had the flexibility to re-prioritize, add, or delete projects from the approved list, depending on a project's merit and conditions.

METHODS TO FUND IMPROVEMENTS AND CONTROL COSTS

The District confirmed that the funds acquired would be adequate for approximately five years before additional revenues would need to be developed. In order to minimize immediate fiscal impacts to landowners, the District bonded or borrowed the initial capital funds and will repay them over time. This will help protect the integrity of the District's conveyance system and make sure that water users will continue to receive surface water supplies, when available.

Methods to fund improvements and control costs include:

- Bonding
- Outside grants and contributions
- Utilize district workforce
- Focus improvements on mainlines and laterals
- Retrofit existing weir structures
- Low tech improvements
- Limited automation

Bonding

The District needed additional revenues to maintain the level of service that the property owners have historically been accustomed to receiving, as well as maintain the water rights for future use. The improvement costs are estimated at $18.5 million, with $10.3 million of the funding coming from bonds. In order to minimize the immediate fiscal impacts to landowners, the District decided to bond the initial capital funds and repay them over time. The District's Board of Directors and the landowners approved a supplemental assessment that equaled an additional $1,651,730 in 2006 and indexed annually to approximately $3,681,511 in 2010.

Outside Grants and Contributions

In addition to the bonding funds, the District expected to receive approximately $4.6 million through grants and contributions from local agencies. The District expects to receive several grants from federal and state agencies such as the United States Bureau of Reclamation (USBR) and the California Department of Water Resources (DWR). In recent years, the District has been successful in obtaining close to $6.0 million in grant funding from sources such as the DWR Proposition 13, DWR AB 303, USBR Challenge Grant, USBR Water Efficiency and Water Marketing, among others. The District also planned on receiving funding contributions from local agencies such as the Cities of Fresno and Clovis, the County of Fresno, as well as the Fresno Metropolitan Flood Control District (FMFCD). While $4.6 million is a large sum to expect, most of the projects were already planned and the contribution percentages were tentatively agreed upon by the agencies. An example of this was the Fancher Flume Replacement/ Enterprise Canal Improvement Project that totaled approximately $900,000. The District received a $300,000 USBR grant and the remaining project costs were split by four agencies with a breakdown as follows: District – 31.9 percent, City of Fresno – 26.4 percent, FMFCD – 20.6 percent, City of Clovis – 14.3 percent, and County of Fresno – 6.7 percent.

Utilizing District Workforce

In addition to bond funding, grants, and contributions received, the District expected to receive approximately $3.5 million by utilizing District forces and equipment. The in-house labor included surveying, engineering, and construction, where possible. Due to the specialized nature of the majority of the capital improvements, the District has been able to minimize costs and construct a greater number of projects by utilizing its construction forces. District staff is planning to utilize in-house forces to construct some of the projects, but will continue to focus its resources primarily on maintenance. The District developed a Project Manager position to oversee the majority of the in-house and contracted projects. The District was able to promote within for this position and the staff member had 15 years of District experience including seven years as its Construction Inspector. Because the District did not want to forego routine maintenance, it hired several temporary laborers to assist with less skilled work such as removing trash from the urban areas, as well as removing trees and vegetation from canals that had been neglected for the past few years. With the addition of the temporary employees, the District was able to shift several of the more experienced FID employees to work on construction crews.

Focus Improvements on Mainlines and Laterals

One of the three goals of the Three-Year MFUP was to improve landowners' ability to better manage the surface water supply, which would be accomplished by upgrading a portion of the existing turnout gates. Although the District had developed an extensive list of projects over the previous seven years, it recognized the need to improve deliveries and to research improved measurement at turnout gates. The District hired the Irrigation Training and Research Center (ITRC) who developed a report on the modernization improvements necessary to attain the goals laid out in the Three-Year MFUP. The District had previously determined to retrofit existing measuring devices that consisted mainly of meter gates, orifice plates and a small number of propeller meters. The District also previously decided to experiment will several flow meters, but installed only 25 due to the unproven technology. Based on the ITRCs report, the District instead focused on better level control in the mainlines and medium laterals. The ITRC also developed the concept of the Mill-Herndon Canal Superhighway, as shown in Figure 1, which would move water more quickly from the east side of the District, through the Fresno-Clovis metropolitan areas, out to the west side of the District, which is primarily rural agricultural land.

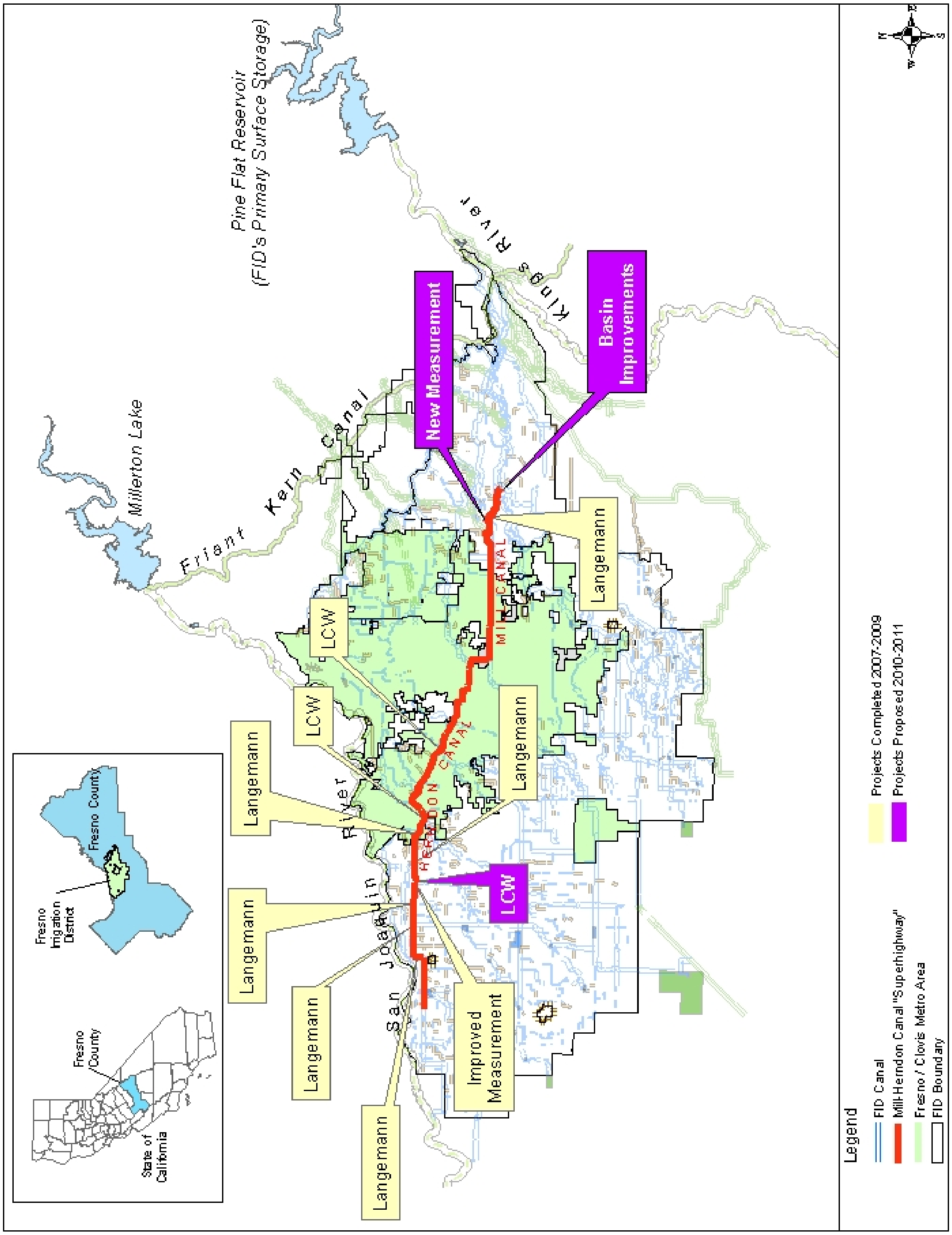


Figure 1. Mill – Herndon Canal "Superhighway"

Retrofit Existing Weir Structures

The District was able to maximize funding and improve additional sites by retrofitting the existing weir structures. A picture of a standard District weir structure is shown in Figure 3. Although most of the District's 2,500 weir structures have not been improved since they were constructed in the late 1800s and early 1900s, it was determined that the majority would last for many more years. The majority of the projects will be retrofitted with either an ITRC Flap Gate or Long Crested Weirs as shown in Figure 2 and Figure 4. It was determined that the ITRC Flap Gates and Long Crested Weirs would not create enough stress or strain to the existing weir structure to warrant a completely new structure. Many of the weir structures were in disrepair and did require some additional repairs and in isolated cases complete replacement. The District will save a considerable amount of money by utilizing the existing structures.

Figure 2. Typical Weir Retrofitted with ITRC Flap Gate

Low Tech Improvements

While the District has added approximately 60 sites to its SCADA system over the past 15 years, only 32 sites are fully automated control sites. This leaves 2,468 standard weir structures remaining. The standard weir has not been improved since they were first constructed in the late 1800s and early 1900s. The District did not intend to fully automate the majority of the sites and instead decided to focus on better level control in the canals, the biggest reason being that the costs are prohibitive. The District has chosen to construct mainly "low tech" structures such as ITRC Flap Gates and Long Crested Weirs, and shown in Figure 2 and Figure 4. It was later determined that the ITRC Flap Gate would not work in most locations due to a lack of head loss across the weir structure. At this point, the District decided to retrofit the majority of the existing structures with a long crested weirs. At the end of the Thee-Year MFUP, the District anticipates constructing approximately 100 long crested weirs and 15-20 ITRC Flap Gates.

In addition to being a cost-effective solution, the long crested weir is a proven technology to control water levels. As stated in ITRC's 2006 report on Long Crested Weirs, they allow the safe passage of a large flow rate with relatively small increase in water surface elevation upstream of the structure. The concept of a long crested weir is simple: Provide more weir length than is possible with typical weirs. A typical weir is installed across the canal with the crest perpendicular to the centerline of the canal. The additional weir length makes it possible to pass the design flow rate with smaller heads. From an operations point of view, this means that large changes in flow rate over the long crested weir will result in smaller changes in head and small changes in flow into the lateral or farm turnouts upstream of the weir. Installation of long crested weirs can result in turnouts that are relatively insensitive to changes in the canal flow. If the turnouts and check structures do not have to be re-regulated each time there is a change in flow rate, it will take less labor to operate the system. Greater flexibility in water deliveries can be accomplished with less labor.

The District worked with the ITRC staff to refine the design and develop a standard design that included a movable weir crest. The movable weir crest consisted of two boards that would slide into weir board guides incorporated into the catwalk for the Ditchtender to easily operate. The design also incorporated sluice gates that sediment could pass through. In some cases, larger sluice gates were installed on canals that conveyed stormwater or laterals that had different routing schedules. Figure 4 illustrates the catwalk/weir board guide design plus small sluice gates.

Figure 3. Typical Weir Structure

Figure 4. Weir Retrofitted with LCW

Limited Automation

As mentioned previously, the District has no immediate plans to fully automate its system and therefore has chosen to incorporate a more “low tech” plan instead. But, there are many places within the District where it does make sense to automate structures, such as major bifurcations or basin locations. Over the past 15 years, the District has automated several sites each year to help improve water management. While the District has added approximately 60 sites to its SCADA system over the past 15 years, only 32 sites are fully automated control sites. The District plans to add another 40 sites to the SCADA system, for a total of 100 sites. Approximately 40 of these sites will be fully automated control sites.

At bifurcations, the District typically fixes the flow down one lateral with undershot sluice gates controlled with an electric actuator. The other canal is not typically automated and will stay as a traditional weir structure with weir boards. The District will typically construct a Replogle Flume on both canals which will provide an accurate measurement. In recent years, the District has installed several Langemann Gate valves that have been utilized for two different reasons. The Langemann Gate shown in Figure 5 serves as the headgate of a fairly large (350 cfs) canal that can change modes from either flow control or monitor only. During the irrigation season, the District will fix the flows down this particular canal and send the fluctuations to another canal where there are regulation basins. During the winter months when the District is routing flood water, the gate will change modes and will accept the fluctuations and route to a Groundwater Banking Facility downstream.

Figure 5. Langemann Gate Used to Automate Headgate

SUMMARY

Prior to the start of the Three-Year MFUP, it was determined that the additional revenue raised through the supplemental assessment would be adequate for approximately five years before FID would need to raise its rates or generate revenue by other means. In order to minimize immediate fiscal impacts to landowners, the District bonded the initial capital funds and will repay them over time.

The Three-Year MFUP was structured in such a way that it "catches-up" major deficiencies and needs within the District, focusing on deferred maintenance projects and capital improvements. The capital improvements included retrofitting existing weir structures with long crested weirs and automated gates; SCADA and telemetry improvements; improved measurement at lateral headings and selected grower turnouts; regulation and recharge basins; replacement of leaking pipelines; lining problematic portions of open canal; automated trash racks; and improving rights-of-way along open canals.

The District goal was to construct $18.5 million of improvements, with $10.3 million coming from bonds and $8.2 million from outside contributions. After 2 ½ years and as of January 1, 2010 the District has spent approximately 65% of the bond funds and the District was granted another 12 months to spend the remaining 35%. Although the

District encountered many challenges throughout the design and construction phase, the program has been considered a success. To date, the highlights include:

- 105 Regulation Structure Retrofits (76 LCW, 13 ITRC Flap Gates and 16 automated gate valves) and 15 sites remaining;
- 25 Measurement Structures and Devices (5 Replogle Flumes, 5 Mace Meters, 10 Sontek Meters, and 5 miscellaneous structures/devices) with 10 more proposed;
- 40 SCADA sites with 10 more proposed;
- Purchase property for 3 Regulation/Recharge Basins with 2 more proposed;
- 1.7 miles of Pipeline Replacement with several more proposed;
- 1 mile of Canal Lining with several more proposed;
- 30 miles of All Weather Road in Conjunction with the City of Fresno and Clovis Surface Water Treatment Facilities;
- 2 Flume Crossings over Creeks; and
- 4 Auto Trashrakes and 2 large trash booms.

The original plan estimated $8.2 million or 45 percent of the improvements would be funded by outside contributions including federal and state grants, and local agencies. The balance of the funding would utilize in-kind District construction labor and equipment. The original plan estimated that grants and local agency contributions would equal close to $4.6 million while approximately $3.5 million would come from District forces and equipment. As of January 1, 2010, the District has received numerous grants and contributions from local agencies and will be receiving additional grants and contributions over the next 15 months. The District expects the total outside contributions will be close to the original estimate. As expected, the majority of the projects were constructed by the District's construction forces. Due to the specialized nature of the capital improvements the District has been able to minimize costs and construct a greater number of projects relying on the District's construction forces. The District hired Contractors to construct the larger, more complex projects. The completion of these projects will protect the integrity of the District's conveyance system and make sure that water users will continue to receive surface water supplies, when available.

REFERENCES

Provost and Pritchard Engineering Group Engineer's Report for a Proposition 218 Election - 2005

ITRC of Cal Poly SLO RAP Report/Modernization Opportunities – 2005

ITRC of Cal Poly SLO Technical Memo of Turnout Flow Measurement - 2006

ITRC of Cal Poly SLO Report on Long Crested Weirs – 2006

IRRIGATION CANAL IMPROVEMENTS IN NORTHERN UTAH FOR ENHANCING WATER RESOURCES MANAGEMENT

Gary P. Merkley[1]

ABSTRACT

A variety of improvements were made to the irrigation canals in two northern Utah counties during the past several years using state funding meant for enhancements in managing water resources. The improvements included operation and maintenance surveys and recommendations, calibrations of existing flow measurement structures, design and construction of flow measurement structures, measurement of seepage losses, and installation of water level recorders, data loggers, and telemetry systems for improved monitoring of flows. All of the work involved the participation of canal company management, and it was done at the request of the water users and or river commissioner, always in collaboration with state and local government agencies. Some of the results of this work include new flow measurement structures and recording/transmitting equipment, updated measurement structure calibrations, O&M recommendations, detailed GIS-based maps and photographs of the canals and structures, and maps and analysis of seepage losses in several canal reaches.

INTRODUCTION

Cache Valley, in Utah and Idaho, has several irrigation canals which take water from streams and rivers flowing into the valley from the surrounding Wasatch Mountains. Many of these canals were constructed early in the 20th century and most are still earthen, although plans are in place to line several miles of canals in the coming years. As the population of Cache Valley grows, the demand for high-quality water has increased, and the need for improved water management has become more important. Irrigation water users have been especially targeted for water management improvements because they use the largest quantities of water in the valley. The situation is particularly difficult because water measurement capability in the canals is limited, and the operation and maintenance (O&M) budgets of the canal companies have always been very low, often leading to significant deferred maintenance of the infrastructure, including the water measurement installations.

For these reasons, a series of steps were taken over the past seven years to assess the current state of water management in several Cache Valley canals, including surveys to develop improved (and expanded) maps of the canals, the state of the infrastructure, and the current management practices. New operation and maintenance plans were developed for each of the canals, some new flow measurement structures were designed and installed, telemetry and data-logging systems were installed, and seepage losses were quantified. In addition to these measures, calibration checks were performed for each of

[1] Irrigation Engineer, Civil and Environmental Engrg. Dept., Utah State Univ., Logan, UT, 84322; gary.merkley@usu.edu

the existing flow measurement structures in the main canals, and those structures that could no longer function as flow measurement devices have been identified and documented.

All of the main irrigation canals receiving water from the Logan River which flow west and north through the valley were selected for inclusion in the improvement work which has been accomplished, including one canal to the south, and another which takes water from a different mountain stream. The Nibley-Blacksmith-Fork canal conveys water from the Blacksmith Fork River, and the remainder of those included in this work receive water from the Logan River through ten different canals. These are all important canals because the flow in them makes up more than half of the irrigation water used in the valley. In a typical year, the irrigation canals operate from April to early October. The improvement process which was followed comprised several related steps, including the following:

1. Detailed physical surveys of selected canals and related infrastructure;
2. Interviews with canal company personnel and state water officials;
3. Presentations at canal company board meetings;
4. Measurement of canal seepage losses and gains;
5. Preparation of O&M plans to assist canal company managers in achieving improved management of the available water resources;
6. Calibration of existing flow measurement structures in the main canals;
7. Design and construction of open-channel flow measurement structures; and,
8. Installation of telemetry systems and data-loggers to monitor and record water levels at key water measurement locations.

IRRIGATION SUPPLY SYSTEM SURVEYS

Surveys were conducted on most of the Cache Valley irrigation canals to determine the present condition and operability of these canals, including culverts, gates, flumes, and other structures along the main canals. Attention was paid to all the minute physical details by walking in and along the canals, also giving opportunities to meet and talk with some of the water users and canal operations personnel. This type of survey has been called a *Diagnostic Walk-Through* (Skogerboe and Merkley 1996). The diagnostic surveys were conducted on nine irrigation canals that carry water from the Logan River to the west and to the north, and in one case to the south. During the surveys, several hundred digital photographs of flow measurement and water delivery structures, among other significant locations, were taken, along with comments about operations and maintenance issues which were recorded in the field notes at the time each photo was taken. The coordinates of each location were taken with a GPS unit and were also registered in the field notes. One version of the new canal map is presented in Fig. 1.

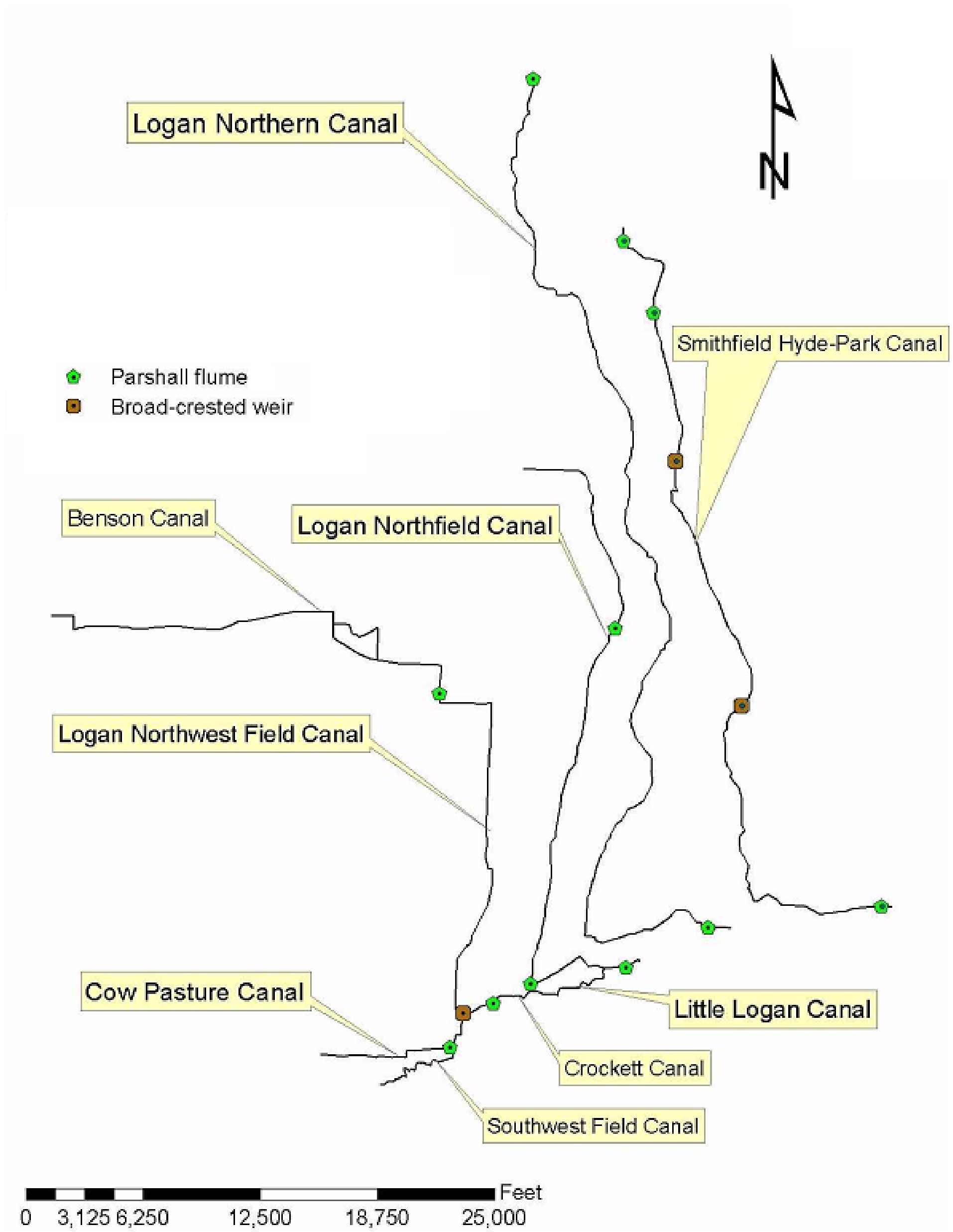


Figure 1**.** Plan view of selected Cache Valley irrigation canals

Interviews and Preparation of O&M Plans

Many of the people involved in the canal operations played an important role in the entire process of development of O&M plans for irrigation canals. In this process, efforts were made to communicate with canal management officials, learn their present methods, strategies, concerns, and problems in achieving the goal of meeting irrigation water requirements within existing budgetary constraints, and with minimum water losses. The observations of the diagnostic surveys were discussed in the interviews with the canal company management and operators, and photographs taken at the time of the survey were shown to them to more clearly discuss key locations in the canals and their importance.

One of the objectives of this study was to develop O&M plans for selected irrigation canals (Tammali 2005). In this plan, all the practical O&M problems identified during the diagnostic surveys were shown with proposed solution approaches. The individual plans also presented a set of guidelines for periodic maintenance of the canals with the active participation of all who are involved in their management. Some of the main maintenance tasks, as observed at the time of the diagnostic surveys, were:

- Periodical removal of weed growth;
- Removal of debris at trash screens;
- Lubrication of outlet gates and head gates;
- Removal of lawn trimmings from the canals;
- Repair of flow measurement structures (where necessary);
- Removal of sediment and tree leaves from the canals; and,
- Repair of side walls damaged by trees growing near the canals.

Calibration of Existing Flow Measurement Structures

The existing measurement structures were calibrated using a current meter to determine the flow rate, taking several measurements, such as upstream and downstream depths at the structure, water surface elevations, and the channel cross section downstream of the structure. The dimensions of all Parshall flumes were checked against the dimensions for standard flume sizes and any discrepancies were noted. Most of the Parshall flumes were found to have standard dimensions and the calibration checks agreed with the standard ratings by ±5% of the discharge.

Some non-functional flow measurement structures were found in the canals. For instance, the Logan Smithfield-Hyde Park canal has three Parshall flumes and two broad-crested weirs (BCWs). One of the three Parshall flumes was observed to be operating under submerged-flow conditions, but the measurement arrangements at the structure were made only for free-flow conditions. At this location there is no provision to measure downstream depth to determine the flow rate under submerged-flow conditions. Thus, the assumption of free-flow at this flume yields large errors in the measurement of flow rate at that location. Thus, it was also necessary to provide some training to the canal management and operators about the correct use of flumes and other measurement structures.

Stormwater Inflow

The most significant operational problem for the Cache Valley canals is storm water drainage into the canals. The development of many new commercial and residential buildings has including the construction of many parking lots which, by themselves, have very little capacity to retain rainwater. The collected storm water often flows directly into the irrigation canals which pass in the vicinity (or downhill) of the developed areas.

This problem is significant because the canals were designed and constructed to supply water, so the capacity reduces in the downstream direction, and they are unable to accept large inflows, especially in the downstream reaches. For example, the Logan Northfield canal in Logan City, which conveys water to the Benson canal, is one of the canals suffering from stormwater inflow problems. Because of stormwater drainage into the canal, the canal company does not have any control on the water flow in the canal when they have surplus water in the canal. There are many problems such as flooding of adjacent lands, sediment deposition, water quality degradation, and channel bed erosion in the canal due to stormwater drainage inflows.

A new broad-crested weir was designed and built by USU on the Southwest Field Canal at the request of the Logan River Commissioner. The structure was built using concrete in an earthen canal, and included an upstream stilling well with an enclosure for water-level recording instrumentation. The new location was equipped with a data logger and a float assembly to record water levels at 15-minute intervals during the irrigation season. The data logger is powered by a 12-volt deep-cycle marine battery, which does not require recharging during the irrigation season, thereby avoiding the need for a solar panel and ancillary equipment.

MEASUREMENT OF CANAL SEEPAGE

Seepage measurements were performed using the inflow-outflow method in several reaches of the canals (Fig. 2), including many repeat measurements at different times during the irrigation season. Discharge measurements were estimated using mini, electromagnetic, and acoustic current meters with rods and the wading method.

Field activities included the monitoring of water levels to observe if the water depth was fluctuating; measurements were only done while the water depth remained constant. Reaches were selected based on accessibility, uniformity of cross section, and predominance of inflow and outflow points at the canal banks. For convenience and accuracy, reaches with numerous water inflow and delivery (turnout) structures were avoided, but inflows and outflows were quantified to distinguish them from seepage loss or gain.

Canal seepage data from the included irrigation canals indicated both spatial and temporal variations. Monthly comparisons of seepage losses within the monitored reaches indicate a higher seepage loss during the late summer, as compared to the spring and early summer. Spatial variations show that most of the canals presented a decreasing average seepage loss in the downstream direction. Between canals it was observed that reaches located in the east part of Logan City presented higher seepage losses than reaches in the canals on the west side. Some canal reaches manifested net seepage losses, while others had net seepage inflow at the time of the measurements. Superposition of the seepage measurements and thematic maps showed a pattern between the estimated canal seepage and the surrounding type of soil, the saturated hydraulic conductivity, the presence of the shallow groundwater and the topography.

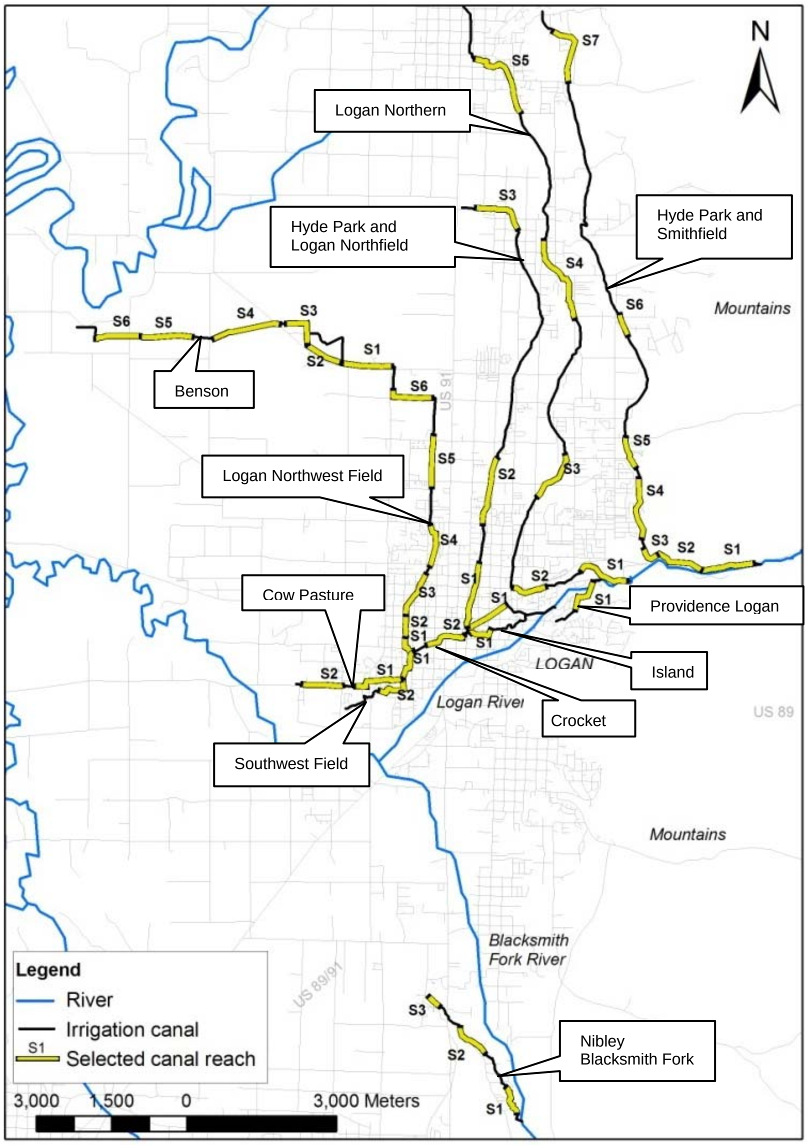


Figure 2**.** Map of the Cache Valley canal reaches in which most of the seepage measurements were made (after Napan et al. 2009)

TELEMETRY SYSTEMS AND DATA LOGGERS

The Utah Department of Water Resources (UDWR) designed and implemented a data acquisition and telemetry system to provide better and more frequent information for the monitoring and documentation of water withdrawals from the Bear River. This was prompted, in part, due to compliance problems with pumping and diversions of water from the river. Over one hundred stations have been set up at pump sites and open-channel measurement flumes along the lower Bear River in northern Utah. Each station is periodically polled, one-by-one, and transmits water depth or flow data to a UDWR station in Logan, Utah, via radio signal. The data are then sent to a UDWR computer in

Salt Lake City, are processed using calibration and other algorithms, and are made available with an approximately 20-minute delay to the public on the UDWR website.

The Utah Water Research Laboratory (UWRL) provided funding for the design and implementation of a data acquisition system at sites in nine of the Cache Valley irrigation canals. The list of sites was determined collaboratively with the Logan River Commissioner after a review of the existing mechanical water level recorders, many of which were found to be in a dilapidated condition. Some of the required SCADA equipment was purchased by the UWRL, and the rest was supplied by the UDWR, but both collaborated on the design and installation at the various canal sites. Canal company personnel and the Logan River Commissioner also assisted in the installations, providing some tools and labor to complete the process.

The design consisted of a data acquisition and telemetry system, along with a power supply, at nine existing Parshall flumes and broad-crested weirs, all of which operate exclusively under free-flow conditions. In locations where the radio signal was unavailable or too weak due to obstructions from trees or buildings, a data logger was used in place of the telemetry system to record, rather than transmit, flow measurement data. This was the case at two of the seven sites.

A wooden small shelter encloses most of the data acquisition system at each site, protecting it from the weather and vandalism. The shelter was placed over a stilling well and the depth of water in the well corresponds to the depth in the canal on the upstream side of the flume or broad-crested weir. A digital shaft encoder was installed in the shelter and was connected to a pulley with a float and counterweight which was placed inside the stilling well. After installation, the readings from the shaft encoder were calibrated to the actual water level, based on the elevation of the upstream flume floor (or the sill elevation, for BCWs), represented as a linear equation in the data logger.

A network of repeater towers was necessary to transmit flow data from various locations in Cache Valley to the UDWR base station, thereby providing line-of-sight coverage. One repeater tower was installed on the roof of the main engineering building at USU, permitting coverage in a previously “blind” region along the Logan River. A radio antenna and transmitter were mounted on a steel pole which was anchored into the ground next to each shelter, and at one site the antenna was mounted on the roof of a building adjacent to the canal. Water level data are transmitted to the UDWR base station at regular intervals (approximately every 20 minutes) during the irrigation season.

The data loggers are programmed to record date, time, battery voltage, water depth, and flow rate. To determine the flow rate, the appropriate free-flow calibration equation was programmed into the data logger using coefficients and exponents obtained from calibration measurements for the specific flume or weir at that site. Records and observations confirm that the flumes at each of the nine locations never operate under submerged-flow conditions during the irrigation season.

Once the UDWR system has called (or attempted to call) every station, it automatically cycles back to the first station and the process repeats. If the system runs through a complete cycle of all stations in under five minutes, a sleep mode is invoked until the five-minute period is reached, at which point the call cycle begins again. However, the cycle has never been completed in less than five minutes in this system, especially with the recent addition of several new stations.

Four of the stations do not have radio reception and are manually integrated into the system when the Logan River Commissioner gathers the data during the normal weekly monitoring routine. The data can either be downloaded by the use of a data card that inserts directly into the data logger or by hooking the data logger up to a PC for direct download. Two of these four stations have solar panels to trickle-charge the small battery which powers the data logger, and the other two have deep-cycle marine batteries without solar panels. The two stations without solar panels were experiments to determine whether a deep-cycle battery could power the data loggers for an entire irrigation season, avoiding the need for solar panels which might be shaded by trees at the site and which can be subject to vandalism and theft. Thus far, the deep-cycle batteries have lasted all season, and are recharged during the off-season.

RESULTS AND DISCUSSION

Administrators of the lower Bear River project have stated that the publicly available flow measurement data has solved a number of water disputes between farmers. And the director of the UWRL commented on how the system has improved management during years of drought and reduced water disputes (McKee and Khalil 2006). The addition of flow measurement data from the nine new sites has also improved monitoring and management, including the resolution of occasional disputes over water rights issues, flood damages to adjacent properties, and compliance with the canal operating plans.

The canal improvements implemented in Cache Valley have shown how public and private organizations can successfully cooperate to improve water management and conservation. The UDWR provided the technology and design of the telemetry system, the UWRL provided funds to complete the project, and local canal companies provided labor and tools to assist with the equipment installation. And the diagnostic surveys and O&M plans were developed in direct participation with the canal companies and Logan River Commissioner, also enjoying the support and assistance of some of the affected municipalities in the valley. As a result, the involved organizations have gained valuable experience in cooperating to improve water management, water monitoring, and documentation of management practices.

SUMMARY AND CONCLUSIONS

Through the combined efforts of the UDWR, UWRL, USU, and various canal companies, the lower Bear River SCADA system was expanded to include several canals which take water from the Logan River. Digital shaft encoders, radio transmitters, and data loggers were installed to provide accurate and timely data to water managers and water users through the UDWR webpage at some sites, and through data loggers at others. The implementation of this project has already resulted in improved water regulation throughout Cache Valley, helping to make a positive impact on the local water supply and water conservation in general. Indeed, the cooperation of public and private organizations and agencies is an excellent example of how to use all available resources collaboratively to enable enhanced water management.

REFERENCES

McKee, M., and Khalil, A. (2006). "Real-Time Management of Irrigation Facilities in the Sevier River Basin." Presentation to the Sevier River Water Users Assoc.

Napan, K., Merkley, G., and Neale, C. (2009). Seepage Evaluations in Cache Valley Irrigation Canals. Paper presented at the USCID conference in Salt Lake City, UT. November.

Skogerboe, G., and Merkley, G. (1996). Irrigation Maintenance and operations learning process. Water Resources Publications, Colorado, USA. 358 pp.

Tammali, B. (2005). Maintenance and operation plan development for Logan River. Graduation thesis, Utah State Univ., Logan, Utah.

FUNDING PROGRAMS FOR WATER MANAGEMENT AND EFFICIENCY MEASURES

Sheri A. Looper[1]
Tracy S. Slavin[2]

ABSTRACT

The Bureau of Reclamation (Reclamation) has played a significant role, in partnership with water users, States, and other interested parties, to help improve water resource management and the efficiency of water use in the western United States. The Mid-Pacific Region of Reclamation has three water conservation grant programs to establish these partnerships, which provide funding opportunities for infrastructure improvements and delivery flexibility including, but not limited to, activities such as canal lining and piping, system automation, and water banks. Funding opportunities include the Water Conservation Field Services Program, the CALFED Water Use Efficiency Program, and the Water Marketing and Efficiency Challenge Grants. Each grant program has a unique focus while contributing to the overarching goal of water conservation. These grant programs provide tools to urban and agricultural delivery entities to manage their water more effectively, and thus use the same amount of water to meet additional or unmet needs or conserve by decreasing consumptive use.

INTRODUCTION

Reclamation was created by an act of Congress in 1902 to develop and provide water resources for the arid Western United States. Differentiated into 5 regions, Reclamation encompasses 17 states (Figure 1), and is the largest wholesale water supplier in the United States. Since 1902, Reclamation has constructed over 475 major structures including Hoover Dam on the Colorado River and Shasta Dam on the Sacramento River. Beginning in the 1980's environmental concerns and population growth in such areas as Los Angeles, San Francisco, Las Vegas, and Phoenix required Reclamation to expand its mission to *"manage, develop, and protect water and related resources in an environmentally and economic sound manner in the interest of the American public."*

With much of the Western United States historically experiencing moderate to extreme drought conditions, achieving Reclamation's mission is challenging due to the limited water supply needs to meet environmental, agricultural, and urban needs. California is in its third consecutive dry year, and the United States Department of Agriculture has designated 53 of 58 California counties as agricultural disaster areas. In 2009, Reclamation had only a 10% water allocation to some agricultural customers, and was close to delivering only the amount of water necessary to meet human health and safety needs for the urban sector. Californians are experiencing the pain of drought through lost

[1] Water Conservation Specialist, Team Lead, Bureau of Reclamation, 2800 Cottage Way, Sacramento, California 95825; SLooper@usbr.gov
[2] Branch Chief, Bureau of Reclamation, 2800 Cottage Way, Sacramento, California 95825; tslavin@usbr.gov

jobs and severe economic hardships in what used to be farm rich regions of the Central Valley.

Figure 1. Map of Reclamation's 17 Western States with the five regional boundaries.

In California, water supply is at the foremost of everyone's mind, including farmers, recreationists, fish and wildlife managers, and lawmakers alike. State and Federal governments are taking critical steps to help ease water supply strains in the face of shortages, population growth, and competition. Historically, competing stakeholders have debated the issue of storage versus demand management and water conservation. Through recent legislative acts, it has become clear that water conservation and water use efficiency are front-runners in helping to mitigate the immediate water challenges in the West.

RECLAMATION'S WATER CONSERVATION AND WATER USE EFFICIENCY PROGRAMS

For purposes of this paper, "water conservation" is defined as cost effective and environmentally sound measures, technologies, programs, and incentives that result in improved, efficient management of water resources for beneficial uses, preventing waste or accomplishing additional benefits with the same amount of water. Examples of water conservation measures include, but are not limited to, Supervisory Control and Data Acquisition (SCADA) systems for improved water management and deliveries, canal lining to prevent seepage, tailwater return systems for water reuse, leak detection programs, irrigation retrofits, and water efficient appliance rebate programs.

Reclamation has the responsibility, in partnership with water users, States, and other interested parties, to help improve water resource management and the efficient use of water in the Western United States. Reclamation's commitment to conservation through grants was solidified with the passage of the Omnibus Public Land Management Act of

2009, Public Law 111-11. Whereas Reclamation struggled in the past for authority to award financial assistance for water conservation projects/programs, Public Law 111-11, Section 9504, provides the Secretary with long-term authority for entering into financial assistance agreements for water conservation.

Public Law 111-11 specifies that water conservation grants shall not exceed 50 percent of the project's cost and cannot exceed $5,000,000. However, federal funding maximums vary depending on the program and the region that is administering the program. Funding amounts/maximums are further discussed under each program title.

Reclamation has three water conservation grant programs designed to establish conservation partnerships: Challenge Grants, the CALFED Water Use Efficiency (WUE) Grant Program, and the Water Conservation Field Services Program (WCFSP). Through these programs, Reclamation provides funding to irrigation districts and urban water agencies for water management improvements that accelerate the implementation of conservation activities. These grants provide tools to water districts to better manage their water, and thus conserve by diverting less, or using the water more efficiently within their service area. Each grant program has a unique focus (Table 1) while contributing to the overarching goal of water conservation.

Challenge Grants

Reclamation presented The Water Conservation Initiative in 2009 as part of the strategic plan for implementing the Secure Water Act. The Secure Water Act authorized Reclamation to establish a climate change adaptation program that includes the facilitation of basin-wide water management improvements. The Water Conservation Initiative will develop incentives for the implementation of best management practices for water conservation. The Water Conservation Initiative also includes Challenge Grants (formerly Water 2025 and Water for America Challenge Grants) that focus on the following:

1. Water use efficiency projects that produce "real water savings,"
2. Water markets and water banks,
3. Improving water management by increasing the use of renewable energy and operation flexibility,
4. Addresses endangered species or other environmental concerns,
5. Water treatment pilot or demonstration projects to create new water supplies from brackish, saltwater, or otherwise unusable waters,
6. Planning or research activities designed to conserve or increase the efficiency of water use and the development of climate analysis tools.

In 2010, there is an increased focus on "real water savings."

Although Reclamation unveiled the Water Conservation Initiative in 2009, Challenge Grants were initiated in 2004 as part of the Water 2025 Initiative; the first Reclamation-wide program that focused attention on the complex water issues of the West by providing a forum for public discussion so that decisions could be made in advance of a water supply crises. Challenge Grant projects focused on modernizing aging water delivery infrastructure, water banking/marketing, and improving water use efficiency and conservation. Since 2004, the Challenge Grant program has funded 167 projects that when coupled with local cost-shares, represent approximately $60 million in water system and water management improvement across the West. These projects create new water banks, promote the use of advanced technology to improve water management and increase collaboration among Federal, State, tribal, and local organizations.

Challenge grants are competed Reclamation-wide, and are typically capped at $300,000. In 2009, the Mid-Pacific Region of Reclamation received 10 of the 23 grants awarded. Projects included groundwater banking, new construction, and canal lining (Figure 2).

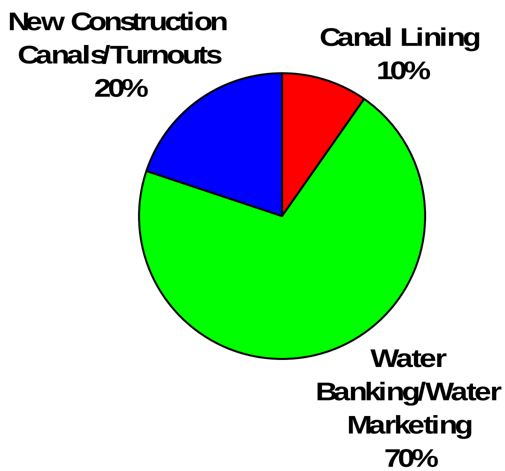


Figure 2. Percent of Money Awarded for 2009 Challenge Grants

In 2009, 10 grants totaling $3 million were awarded to Mid-Pacific Region water purveyors through the Challenge Grant Program. Federal awards were $300,000 each. The projects' potential acre feet of water conserved or better managed is 57,357.

The Water Conservation Field Services Program

Before the development of Challenge Grants, the WCFSP was Reclamation's primary source of water conservation grants. The WCFSP is a locally administered and competed program, designed to provide technical and financial assistance for water management planning, implementation of best management practices, demonstration projects, and conservation education.

The WCFSP commenced in 1997, to aid in Reclamation Reform Act of 1982 (RRA) compliance. RRA, Section 210, stated that Reclamation was to "encourage the full consideration and incorporation of prudent and responsible water conservation measures in the operations of non-federal recipients of irrigation water from Federal Reclamation projects…" As a result, all agricultural, municipal, and industrial water contractors that entered into contracts pursuant to Federal Reclamation law or the Water Supply Act of 1958, were required to provide Water Management Plans (Plans). The completion of these Plans became a provision in the water supply contracts and each Plan had to include the following:

- Definite goals
- Water conservation measures
- Time schedule for meeting objectives

Approximately 10 years after the passage of RRA, Reclamation was criticized for their contractors' lack of water conservation efforts, and the Natural Resources Defense Council and other environmental groups filed suit against Reclamation, stating that Reclamation was not effectively implementing the water conservation measures of RRA. In 1996, Reclamation entered into a Settlement Agreement to fulfill its legal responsibility under Section 210 of RRA, and as a result, the Commissioner of Reclamation issued a new Reclamation-wide policy on water conservation planning. To ensure efficient use of federal water, Reclamation was to work directly with individual districts to develop water conservation plans and provide technical and/ or financial assistance in the implementation of water conservation programs/projects and new technology.

A key element in the settlement agreement was the initiation of the WCFSP, designed to encourage and support water conservation as a non-regulatory incentive based program for financial and technical assistance. The goals of the WCFSP were outlined as follows:

1. Ensure development and implementation of high quality water conservation plans.
2. Demonstrate innovative technologies that conserve water.
3. Implement effective water conservation measures throughout Reclamation States and advance improved water management on a regional and statewide basis.

Over the years, the WCFSP has evolved to accommodate the more challenging societal pressures on limited water supplies. At the WCFSP inception, Reclamation awarded grants on a non-competitive basis. Water districts submitted a letter of request that described the project, and if Reclamation's Area Office Water Conservationist Specialist deemed the project beneficial, funds were generally awarded on a cost share basis and did not exceed $25,000. However, in Fiscal Year 2005, the WCFSP became a competitive process, advertised on grants.gov, and new legislation required that the federal cost share per project be capped at 50% of project costs. In 2009, the WCFSP selection criteria underwent a significant change. In previous years, each region of Reclamation identified their own selection criteria for the competitive process; however, each region now incorporates Reclamation-wide selection criteria and grading scales that emphasize water conservation planning and implementation of efficiency improvements. In addition to the Reclamation-wide selection criteria, each funding announcement could include additional criteria developed at the regional or local level to account for local water conservation priorities and goals.

Maximum funding for the WCFSP is $100,000 per grant (not to exceed 50% of the projects cost); however, some of Reclamation's regions choose to limit funding to a lesser amount to effectively meet local needs.

In 2009, the Mid-Pacific Region awarded 16 grants for meter testing, leak detection, measurement and flow regulation, irrigation evaluations, and education (Figure 3).

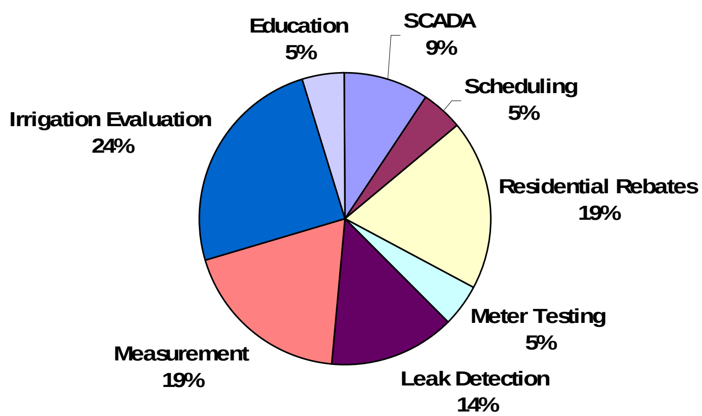


Figure 3. Percent of Money Awarded for 2009 WCFSP Grants

In 2009, 16 grants totaling $534,000 dollars were awarded to MP-Region water purveyors through the WCFSP Program. Federal awards ranged from $25,000 to $84,000. The projects' potential acre feet of water conserved or better managed is 34,000.

Since the program's inception, the Mid-Pacific Region has awarded over 400 WCFSP grants for projects such as canal lining and piping, irrigation scheduling, system delivery, system modernization, residential rebate programs, education, and measurement. Including water district contributions, the WCFSP has resulted in over $25.6 million invested in water conservation projects in the Mid-Pacific Region alone.

The CALFED Water Use Efficiency Grant Program

In addition to participating in Challenge Grants and the WCFSP, the Mid-Pacific Region also administers the CALFED WUE Grant Program. CALFED is a combined State of California and federal program focused on the restoration of the Delta's fragile ecosystem while improving water supply reliability for urban and agricultural water users. The goal of the WUE Grant Program is to accelerate the implementation of cost-effective actions that provide state-wide benefits through water conservation. Water use efficiency from districts linked to the Bay-Delta water supply can result in significant benefits to water quality, water supply reliability, and in stream flows.

In 2009, the Mid-Pacific Region awarded 16 grants for hardware retrofits, SCADA, Leak Detection, rebates, ET controllers, and distribution system improvements (Figure 4).

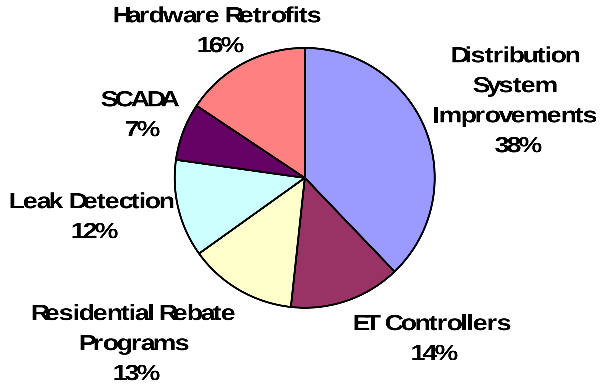


Figure 4. Percent of Money Awarded for 2009 CALFED Grants

In 2009, 16 grants totaling $5.3 million were awarded to Mid-Pacific Region water purveyors throughout the State of California. Federal awards ranged from $79,000 to $1 million. The projects' potential acre feet of water conserved or better managed is 22,524.

Since the inception of the CALFED WUE Grant Program in 2006, Reclamation has awarded 47 grants to water purveyors throughout California. With local cost-share contributions, Reclamation's CALFED WUE Grant Program has resulted in over $29.6 million being invested into water use efficiency projects statewide.

Table 1. Reclamation's Grant Program Attributes

Program	Program Attributes
Challenge Grants	Competed Reclamation-wide and focus on quantifiable water savings, water banks, water markets, and other efficiency measures to address the challenges posed by drought, climate change, energy demands, expanding populations, and increased environmental needs.
WCFSP	Locally administered program, designed to provide technical and financial assistance for water management planning, implementation of best management practices, demonstration projects, and conservation education.
CALFED	Designed to provide benefits to the Bay-Delta Estuary through water use efficiency activities.

In 2009, The CALFED WUE grant program, the WCFSP, and the Challenge Grant program significantly contributed to West-wide (17 western states) water conservation (Table 2). Although all programs play a significant role in Reclamation's efforts to promote better water management, recent budgetary trends support an all-West-wide encompassing conservation approach (Figure 5). In recent years, Reclamation has reduced the dollars spent on the WCFSP, Reclamation's deep-rooted, locally administered conservation program, while other programs continue to grow. This approach has several positive attributes such as the ability to award more large-scale projects, but it also poses challenges in that water purveyors are now competing amongst other water purveyors from the 17 western states.

Table 2. 2009 Water Conservation Expenditures and Benefits

Grant Program	# Projects Funded	Federal $ Invested	$ of Local Cost Share	Acre-feet Conserved or Better Managed
Challenge Grants*	23	4,672,493	14,478,152	74,228
WCFSP	16	533,875	1,332,802	33,996
CALFED	16	5,584,131	7,763,907	22,524
Total	**55**	**10,790,499**	**23,574,861**	**130,748**

*This number represents all Challenge Grants Reclamation-wide, not just within the Mid-Pacific Region.

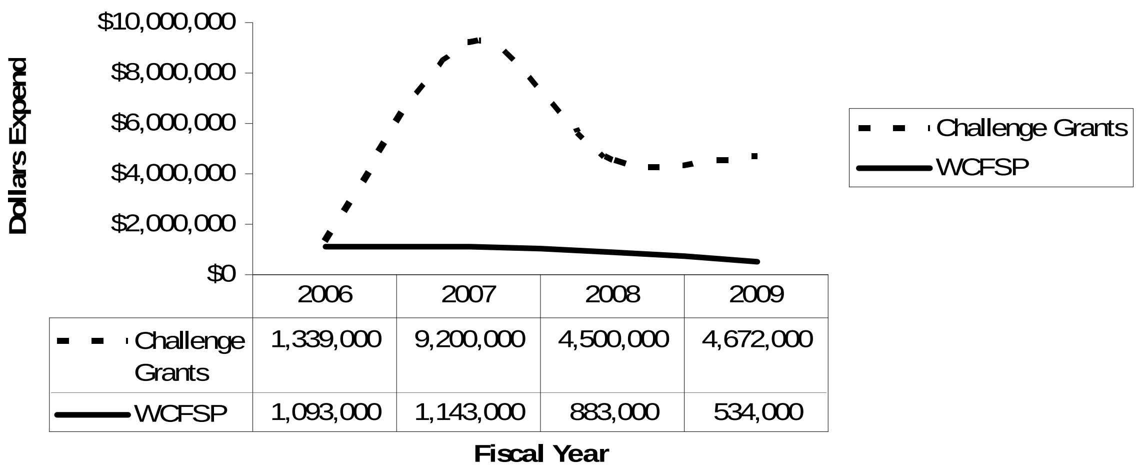


Figure 5. Historical dollars Spent on conservation projects per program from 2006-2007.

As can be seen in Figure 5, the availability of funds is shifting from locally administered programs (WCFSP) to Reclamation-wide programs (Challenge Grants).

With such large dollar amounts being spent on water conservation programs, there is an increased accountability to prioritize expenditures and determine the most cost-effective means of using limited funding resources. In the water management industry, this requires analyzing the cost versus the benefits of projects that focus on water demand management to determine which practices, in which situations, result in the best use of funding.

Prior to 2006, Reclamation had no standardized methods to quantify the results of water conservation projects even though initial estimates of water savings were required. In order to quantify benefits of a project, determine effectiveness of water management efforts and summarize the overall effectiveness of the WUE grant programs, Reclamation, in cooperation with CALFED, developed performance measures to compare pre- and post-project water use data. By implementing these performance measures, one can calculate the anticipated project benefits and verify results, i.e. water conserved after project implementation.

The effort to quantify benefits is consistent with laws such as the Government Performance and Results Act of 1993 (GPRA) and with the federal government's Program Assessment Rating Tool (PART) which require federal agencies to strategically plan according to program objectives and to track and report their performance. GPRA and PART promote measurable results and assess performance using program results. Developing water management performance measures for Reclamation's WUE projects adheres to GPRA and PART requirements and will allow Reclamation to measure program effectiveness and to calculate the costs and benefits of conservation efforts. Performance monitoring will give output measurements that are expressed in a quantifiable manner, which will give water managers real data to use when evaluating the financial feasibility of future projects.

Currently, quantifiable information for water use efficiency projects is limited, and varying measurement methodologies make it difficult to compare benefits from program to program, or location to location. Standardizing quantification methods for measuring WUE benefits with performance measures will allow comparison of the results from varying grant programs such as Challenge Grants, the WCFSP, and CALFED WUE Program.

Specific performance measures were developed for various WUE projects including canal lining or piping, installation of measurement devices, SCADA, system controls to decrease spillage, drainage reuse projects, landscape evapotranspiration controllers, irrigation system improvements, water marketing, and ground water banking. Types of data collected will include quantification of seepage, spills, water deliveries consumptive use, crop evapotranspiration, improvements in delivery flexibility, pumping volumes, and end of season water storage. Table 3 is an abbreviated version of Reclamation's performance measures for canal lining, measuring devices, and data acquisition projects. The complete performance measures document is online at http://www.usbr.gov/mp/watershare/documents.

There are limitations to the performance measures. In some cases, baseline data may not be available for post-project comparisons. One may face challenges quantifying the direct benefits for certain projects such as measurement and automation since no previous data on water consumption exists for that area. It is also impossible to come up with a "one size fits all" performance measure for each project type. In addition, verifying water conserved from certain projects may take several years due to temporal and spatial differences.

Table 3. Examples of drafted performance measures for WUE projects.

Action	***Pre-project estimations of baseline data***	***Post-project verification methods***
Canal Lining or Piping	▪ Ponding Tests: Conduct ponding tests along canal reaches proposed for lining or piping. ▪ Inflow/Outflow testing: Measure water flowing in and out of the canal reach, taking evaporation into consideration.	▪ Using ponding tests, compare pre- and post-project test results to calculate water savings. ▪ If ponding or inflow/outflow tests cannot be performed, compare estimated historic seepage and evaporation rates for the lateral length of the canal to the post-project seepage and evaporation. ▪ Compare ratio of historic diversion-delivery rates. Also include a comparison of historical and current canal efficiencies. ▪ Record reduction in water purchases by shareholders and compare to historical water purchases.
Measuring Devices	▪ Pre-project estimated savings are difficult to measure; however, one can collect historical data on water use to estimate the amount of delivered water.	▪ Compare post-project water measurement (deliveries or consumption) data to historical water uses. ▪ Compare pre- and post-project consumptive use by crop via remote sensing information. ▪ Survey users to determine utility of the devices for decision making. ▪ Document rate structure changes such as volumetric or tiered water pricing due to the use of measurement devices (assumes non-metered to metered district) so that water users are billed for actual water used instead of at a flat rate.
Data Acquisition	▪ Collect data on diversions and deliveries to districts and ditch companies, making estimates if necessary. ▪ Document employee	▪ Calculate amount of increased carryover storage in associated reservoirs. This measure will be more meaningful over a period of years. ▪ Track and record the diversions to individual districts and ditch

	time spent on pre-project ditch/canal monitoring and water control.	companies or district laterals and compare to pre-project diversions. This would show results of improved management if yearly fluctuations in weather are accounted for. ▪ Report delivery improvements- i.e. changes in supply, duration or frequency that are available to end users because of SCADA. ▪ Document other benefits such as less mileage by operators on dusty roads (which saves time and influences air quality) and less damage to canal banks due to fluctuating water levels in canals.

CONCLUSION

Reclamation has historically funded several water conservation and efficiency projects geared towards decreasing water demands in order to meet environmental, agricultural, and growing urban needs. Over the last several years, Reclamation has given hundreds of cost-shared grants to water purveyors and other water related entities for projects such as canal lining and piping, irrigation scheduling, system delivery automation, system modernization, measurement and flow control, residential rebate programs, and water banking.

Investing in new water conservation technology is one of the Secretary of Interior's top four priorities, which is easily addressed through the water conservation grant programs that Reclamation currently offers. Water use efficiency and conservation are key elements in achieving Reclamation's mission, and are critical in the State of California to meet rising demands. Districts that implement water conservation measures either divert or export less or are able to use their water more effectively; that is, using the same amount of water to meet additional or unmet needs. Over the years, grant programs have served as a strong catalyst for the implementation of water conservation measures, and thus have significantly contributed to the improvement of water supply reliability, water quality, and in-stream flows.

Although Challenge Grants, the WCFSP, and the CALFED WUE Grant Program have unique focuses, the core goals are the same: stretch existing water supplies while improving water management and efficiency. Grant programs have been instrumental in transforming water conservation efforts throughout the West, and these programs will continue to be a major catalyst for efficiency implementation measures to help decrease water demands and improve water supply reliability.

ECONOMIC IMPLICATIONS OF WATER SUPPY SHORTAGES: LOCAL AND GLOBAL PERSPECTIVES

Dennis Wichelns[1]

ABSTRACT

The increasing demand for water in all sectors has brought new focus to the use of non-conventional water sources, for both potable and non-potable purposes. Desalination of seawater and brackish water, and advanced treatment of sewage effluent have increased in recent years, particularly in arid regions seeking to enhance their effective water supply. Desalination is used primarily to produce drinking water, although desalinated water is used also for irrigation in some countries. Most of the treated wastewater that is not discharged into receiving waters is used to irrigate landscapes and agricultural crops. In some countries treated wastewater is injected or infiltrated into groundwater as part of an aquifer storage and recovery program. In some areas, such programs expand the supply of water available for irrigation, while also extending the useful life of aquifers that might otherwise be depleted due to excessive pumping. We review some of the issues pertaining to the use of desalination and treated wastewater to expand water supplies. We describe several examples in which countries have either gained substantial experience in using desalination or wastewater treatment, or they are considering the potential role of such a program in response to increasing water scarcity. While the potential benefits of using desalinated water and treated wastewater for irrigation and other purposes are substantial, so too is the potential public concern regarding these non-conventional water sources. Educational programs and financial incentives might be required to motivate producers and consumers to begin viewing these sources as safe and affordable alternatives.

INTRODUCTION

In response to the increasing demand for water, many countries and municipalities in arid regions have implemented programs to utilize treated wastewater for potable and non-potable uses. Much of the treated wastewater is used in agriculture, while smaller amounts are used to irrigate landscapes, parks, and sporting fields (Van der Bruggen, 2010). Some is used also to recharge groundwater and to supplement industrial water supplies.

Agriculture and landscaping account for large portions of wastewater use in California and New South Wales, Australia, while environmental uses are most important in Japan (Table 1). Much of the plumbing in large buildings in major Japanese cities is designed to accommodate both treated wastewater and freshwater (Van der Bruggen, 2010). In addition, the price of treated wastewater for domestic users is 16% less than the price of potable water.

[1] Principle Economist, International Water Management Institute, P.O. Box 2075, Colombo, Sri Lanka

Table 1. Proportional uses of treated wastewater in California, Japan, and New South Wales, Australia

California		Japan		New South Wales	
Wastewater use	(%)	Wastewater use	(%)	Wastewater use	(%)
Agricultural irrigation	47	Environmental uses	52	Agriculture (indirect)	39
Landscape irrigation	21	Snow melting	18	Agriculture (direct)	7
Aquifer recharge	9	Agriculture	13	Industrial uses	38
Recreational uses	6	Industry	5	Golf courses	11
Industrial use	5	Toilet flushing	5	Processed water	5
Seawater barrier	5	Uses in plants	5	Others	
Wildlife habitat	4	Others	2		
Others	3				
Sum	100		100		100
Source: Van der Bruggen, 2010.					

Treated and untreated wastewater is used extensively in the Middle East, where freshwater supplies are notably scarce. In Jordan, 95% of the treated wastewater volume is used each year, primarily for irrigation in the Jordan Valley (Van der Bruggen, 2010). In Kuwait, treated wastewater is used for agricultural and landscape irrigation, and for groundwater recharge.

Farmers in Israel currently use an estimated 350 million m^3 per year for irrigating fruits, vegetables, flowers, and field crops (Table 2). The estimated cost of treating wastewater to achieve the minimum level of quality required for irrigating field crops, forage crops, and sod in Israel is \$0.12 per m^3 (Fine et al., 2006). Such water may be used to irrigate fruits and vegetables only in conjunction with crop-specific barriers to prevent contact between the crop and the irrigation water. Protective barriers include plastic ground covers, the use of subsurface drip irrigation, and maintaining an aerial distance between drip system emitters and fruit trees (Fine et al., 2006).

Table 2. Estimated use of water in agriculture in Israel in 2001

Crop Category	Agricultural Water Use	Estimated Wastewater Use
	(MCM / year)	(MCM / year)
Vegetables in open fields	114	30
Vegetables that must be cooked	64	30
Herbs	9	1
Greenhouse vegetables	41	5
Flowers	50	4
Sod	4	1
Orchards (excl. citrus)	387	79
Citrus	186	100
Field crops	91	50
Fodder crops	61	50
Fish ponds	105	0
Animals	27	0
All uses	1,139	350
Note: MCM is million cubic meters.		
Source: Fine et al., 2006.		

In some applications, implementing physical barriers is a less costly approach to using treated wastewater in agriculture than treating the wastewater to the level required for unrestricted irrigation. In Israel, the estimated cost of full treatment to allow unrestricted irrigation is \$0.36 per m^3, while the estimated costs of lower level treatments range from \$0.12 to \$0.21 per m^3 (Table 3). Use of the lowest quality water is prohibited on vegetables and most fruits, but water with a medium level of treatment may be used on deciduous and citrus orchards if barrier methods are implemented. Water receiving a high level of treatment may be used on most vegetables and fruits, with similar consideration for physical barriers. The crop-specific total cost, including the high level of treatment and physical barriers, ranges from \$0.22 to \$0.30 per m^3 (Table 3). This range is notably below the \$0.36 per m^3 cost of treating wastewater to the level that allows unrestricted irrigation.

Table 3. Estimated cost of using treated wastewater, in dollars per m^3, and the number of barriers needed

	Level of Wastewater Treatment			
Crop Category	Low	Medium	High	Unrestricted Irrigation
Cost at the treatment plant	0.12	0.13	0.21	0.36
Number of barriers needed	0	3	2	0
Vegetables in open fields	Pr.	Pr.	0.28	0.36
Vegetables eaten cooked	Pr.	Pr.	0.22	0.36
Herbs	Pr.	Pr.		0.36
Greenhouse vegetables	Pr.	Pr.	0.29	0.36
Flowers in open fields	Pr.	Pr.	0.27	0.36
Sod	0.12	0.13	0.21	0.36
Orchards (excl. citrus)	Pr.	0.18	0.27	0.36
Citrus	Pr.	0.14	0.30	0.36
Grapes	Pr.	Pr.	0.22	0.36
Field crops	0.12	0.13	0.21	0.36
Fodder crops	0.12	0.13	0.21	0.36
Notes:				
Pr. Indicates a prohibited use of treated wastewater.				
Low level treatment	BOD > 60 mg/L, TSS > 90 mg/L			
Medium level treatment	BOD 20 to 60 mg/L, TSS 30 to 90 mg/L			
High level treatment	BOD < 20 mg/L, TSS < 30 mg/L			
Unrestricted irrigation	Removal of pathogens, TSS < 10 mg/L			
Source: Fine et al., 2006				

PUBLIC PERCEPTIONS OF WASTEWATER USE

Public perceptions of wastewater reuse vary across locations and with the amount of information provided to citizens regarding reuse programs. Public acceptance and support for wastewater use generally is stronger with respect to non-potable uses than potable uses (Hartley, 2006). Efforts to persuade citizens to support potable reuse of treated wastewater have failed in several American cities, due partly to inadequate public education and information programs (Hartley, 2006; Marks, 2006). By contrast, potable reuse is promoted vigorously by public officials in Singapore, where as much as 1% of the country’s water supply is obtained through reverse osmosis of reclaimed wastewater (Marks, 2006).

Public support for non-potable uses varies with the reuse activity, as revealed in a set of consumer surveys conducted in three American cities and two Australian cities in the late 1990s and 2000 (Marks, 2006). More than 90% of survey respondents in Monterey, California favor wastewater reuse for industrial purposes and for irrigating parks and golf courses (Table 4). About 80% of respondents favor wastewater use on school grounds, while only two-thirds favor wastewater use on vegetable crops.

Smaller proportions of survey respondents favor wastewater use in Irvine and San Jose, California (Table 4). In Irvine, only 47% of respondents favor using wastewater to irrigate household gardens. By contrast, more than 90% of survey respondents in Sydney, Australia, and 88% of respondents in Perth, Australia favor wastewater use on household gardens. More than 90% of respondents in Sydney also favor wastewater use on vegetable crops and parks.

Table 4. Proportions of survey respondents favoring non-potable reuse of wastewater

	Monterey 1996 n=1,000	Monterey 2000 n=1,000	Irvine 1998 n=400	San Jose 1998 n=400	Sydney 1999 n=1,000
Industrial	95	90	89	79	90
Irrigation:					
Golf courses	98	91	88	83	
Parks	95	91	88	83	97
School grounds	83	76		71	
Vegetable crops	68	63	74	62	94
Household gardens			47		95
Note: The proportions shown do not account for uncertain responses.					
Source: Marks, 2006.					

Public support for wastewater reuse is influenced by perceptions of opportunity costs and information provided by public officials. The city of San Antonio, Texas gained public support for a large-scale wastewater treatment and reuse program by informing citizens that the plan would reduce demand on the fossil aquifer that provides the city's drinking water supply (Hartley, 2006).

Dolnicar and Hurlimann (2010) examine public preferences regarding treated wastewater and desalinated water in Australia. In a survey of 1,495 residents aged 18 or above, most respondents expressed greater concerns regarding treated wastewater than desalinated water. In particular, more respondents stated they were more likely to use desalinated water than recycled water for drinking, bathing, cooking, and several other activities (Fig. 1). Respondents were largely indifferent between the two sources when considering activities such as washing the car, cleaning house windows, and flushing toilets.

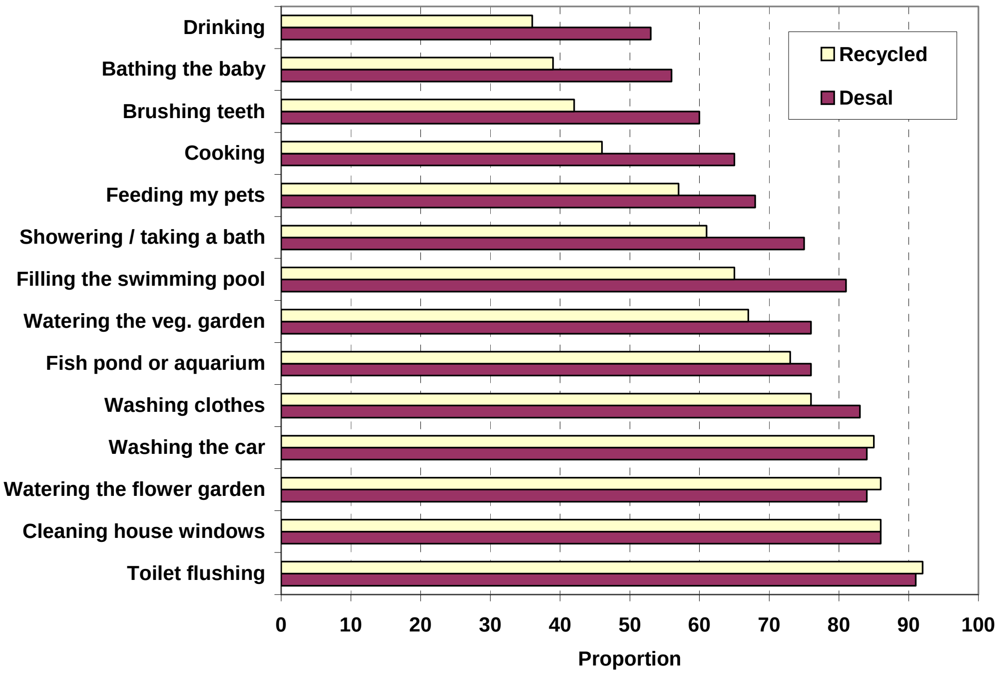


Figure 1. Stated Likelihood of Using Desalinated or Recycled Water
Source: Dolnicar and Hurlimann (2010).

Larger numbers of survey respondents agreed with negative statements regarding treated wastewater than with negative statements regarding desalinated water. For example, 43% of respondents stated they would never drink treated wastewater, while 28% stated they would never drink desalinated water (Fig. 2). Similar results were observed regarding the perceived safety of the two water sources and the perceived health risks. Of interest, more than 70% of respondents stated that wastewater and desalinated water would be suitable for use if scientists approve. Slightly larger proportions of respondents (72% for wastewater and 80% for desalinated water) stated that the water sources would be suitable if using those resources is absolutely necessary.

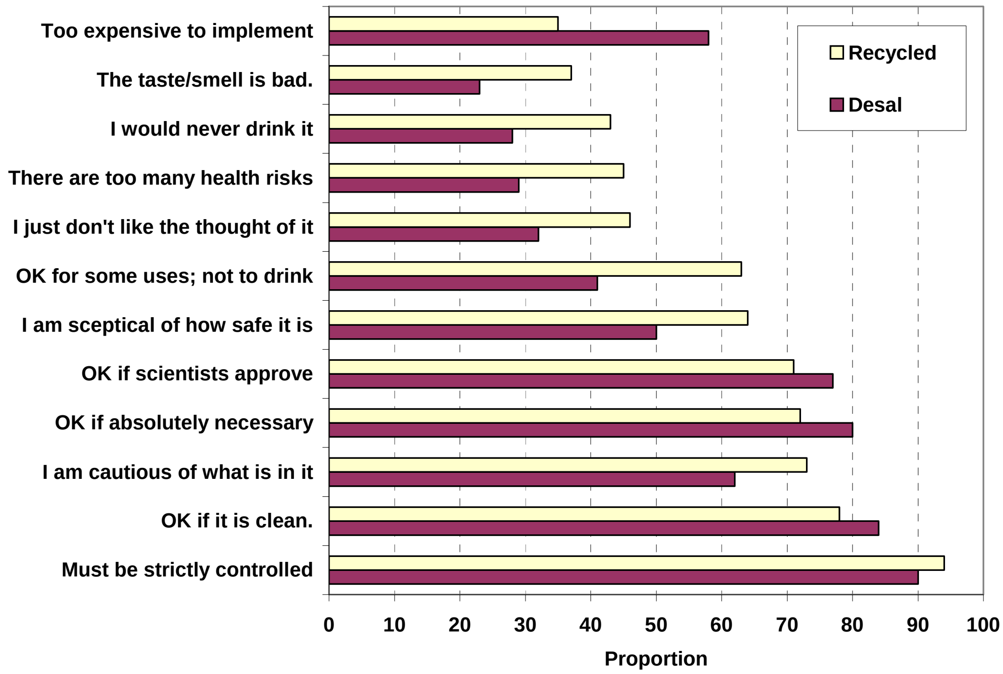


Figure 2. Proportions of Respondents Agreeing with Statements
Source: Dolnicar and Hurlimann (2010).

A COST COMPARISON FROM THE AEGEAN ISLANDS

The primary sources of potable water supply in the Aegean Islands, located between Greece and Turkey, are water imports from Greece, via tanker ships and desalination of seawater via reverse osmosis (Gikas and Angelakis, 2009: Gikas and Tchobanoglous, 2009). To date, there is very little reuse of treated wastewater for potable or non-potable uses. This option is gaining attention, however, given the large energy requirements and the high costs of shipping freshwater and desalting seawater.

Natural water sources on the Aegean Islands are quite limited. Hence, further increases in water supplies to meet increasing demands must come from a combination of water imports, desalination, and wastewater reclamation. Treated wastewater likely would be used primarily for agriculture, landscape irrigation, and non-potable domestic applications (Gikas and Tchobanoglous, 2009). The demand for water in the Aegean Islands and the supply of wastewater are highest during the summer. Thus treated wastewater could be used successfully as a reliable source for agricultural and landscape irrigation. Treated wastewater could be used also for toilet and urinal flushing in residences and hotels, with construction of the necessary distribution system infrastructure.

The estimated costs of alternative water sources in the Aegean Islands vary with the size of production facility, the infrastructure and energy requirements, and the intended final use (Gikas and Tchobanoglous, 2009). The estimated per unit costs of water production are smallest for wastewater reclamation, even when the costs of building the necessary infrastructure are considered (Table 5). The per unit costs for agricultural use range from \$0.65 to \$0.75 per m^3 for a treatment plant producing from 2,500 to 5,000 m^3/day, to \$.75 to \$1.35 per m^3 for a plant producing 100 to 1,000 m^3/day. These costs are quite high in comparison with the cost of irrigation water in most countries, but they are notably lower than the cost of water from alternative sources in the Aegean Islands.

Table 5. Estimated unit costs of water production, including capital, depreciation, energy costs, and operation and maintenance for desalination and wastewater reclamation, as a function of plant capacity, in the Aegean Islands

			Wastewater Reclamation	
Volumetric Capacity	Desalination	Water Imports	Irrigation	Toilet Flushing
(m^3 per day)	(\$ per m^3)	(\$ per m^3)	(\$ per m^3)	(\$ per m^3)
100 to 1,000	1.50 to 3.50	5.00 to 7.00	0.25 to 0.35	0.35 to 0.52
			0.75 to 1.35	0.80 to 1.50
1,000 to 2,500	1.00 to 2.00	5.00 to 6.00	0.15 to 0.20	0.22 to 0.30
			0.60 to 0.75	0.70 to 0.85
2,000 to 5,000	0.75 to 1.25	4.00 to 6.00	0.15 to 0.18	0.22 to 0.27
			0.65 to 0.75	0.75 to 0.85
Note: For wastewater reclamation, the first set of cost estimates in each entry pertains to the cost of wastewater treatment. The second set of cost estimates includes the costs of treatment, pumping, distribution, and storage.				
Source: Gikas and Tchobanoglous, 2009.				

The energy component of the cost of producing water is of interest from two perspectives: 1) Countries that import most of their energy requirements might wish to reduce their dependence on international energy markets, and 2) Countries wishing to reduce their carbon footprint might wish to produce water using relatively small amounts of fossil fuels. Energy accounts for less than 10% of the cost of producing treated wastewater for use in irrigation or domestic applications in the Aegean Islands (Table 6). The energy components in the costs of desalination and water imports are substantially higher. The amount of energy required to produce each unit of water is also substantially higher for desalination and water imports (Table 7).

Table 6. The distribution of costs between capital, energy, and operation and maintenance for alternative water production systems, in the Aegean Islands

			Wastewater Reclamation	
Cost Component	Desalination	Water Imports	Irrigation	Toilet Flushing
	(percent)	(percent)	(percent)	(percent)
Capital	30 to 37	35 to 40	35 to 50	30 to 45
			35 to 50	30 to 45
Energy	40 to 44	40 to 45	3 to 5	4 to 8
			4 to 6	4 to 9
Operation and Maintenance (excluding energy)	20 to 25	20 to 25	50 to 65	60 to 70
			45 to 60	50 to 60
Note: For wastewater reclamation, the first set of values in each entry pertains to the cost of wastewater treatment. The second set of values includes the costs of wastewater treatment, pumping, distribution, and storage.				
Source: Gikas and Tchobanoglous, 2009.				

In sum, the least costly source of additional water supplies in the Aegean Islands is wastewater reclamation, which also requires less energy per unit of water produced. The relative importance of the energy cost component will vary among countries with the sources and costs of energy supplies, but countries might also consider the carbon emission reduction advantages of reclaiming wastewater.

AQUIFER STORAGE AND RECOVERY

Aquifer storage and recovery provides opportunities to enhance the value of treated wastewater, while also improving the management and extending the useful life of limited groundwater resources. Treated wastewater can be injected or infiltrated into confined or unconfined aquifers, and stored there for recovery and use at a later time. Careful management of water quality parameters is required to ensure continuous operation of recharge facilities and to prevent degradation of aquifer water quality. In some cases, adding treated wastewater can improve the quality of groundwater withdrawn from the aquifer.

Table 7. Estimated energy requirements per unit of water produced, as a function of process type and volumetric capacity

			Wastewater Reclamation	
Volumetric Capacity	Desalination	Water Imports	Irrigation	Toilet Flushing
(m^3 per day)	(kWh per m^3)	(kWh per m^3)	(kWh per m^3)	(kWh per m^3)
100 to 1,000	5 to 10	12 to 16	0.08 to 0.15	0.10 to 0.20
			0.11 to 0.18	0.13 to 0.23
1,000 to 2,500	4.0 to 5.0	6 to 10	0.08 to 0.12	0.10 to 0.15
			0.11 to 0.15	0.13 to 0.18
2,000 to 5,000	3.5 to 4.0	5 to 8	0.05 to 0.10	0.06 to 0.12
			0.08 to 0.13	0.09 to 0.15
Note: For wastewater reclamation, the first set of energy estimates in each entry pertains to the energy for wastewater treatment. The second set of estimates includes the energy for treatment, pumping, distribution, and storage.				
Source: Gikas and Tchobanoglous, 2009.				

An Example from El Paso, Texas

The City of El Paso, Texas began operating an aquifer storage and recovery program, utilizing treated wastewater, in 1985. The program involves one of the City's wastewater treatment plants, which can receive up to 38,000 m^3 per day. The plant injects a portion of the water it produces into the Hueco Bolson, which is an unconfined and semi-confined aquifer, providing much of the region's water supply (Sheng, 2005). El Paso derived about one-third of its water supply from the Hueco Bolson in 2002, while the aquifer is the sole source of drinking water for Ciudad Juarez, an adjacent city located across the Rio Grande in Mexico.

Given the importance of the Hueco Bolson as a major source of drinking water and the persistent shortage of water in this arid region, the recharge program was designed to increase potable water supplies with minimum risk (Sheng, 2006). This objective generated two operational criteria: 1) Maximize the recovery of stored water to minimize costs, and 2) Ensure adequate aquifer storage time to allow for adequate purification of the stored water. The spacing and operation of injection and recovery wells were designed in accordance with these criteria.

During the first 18 years of operation, the treatment plant injected 74.7 million m^3 of reclaimed wastewater, about two-thirds of its production, into the Hueco Bolson (Sheng, 2005). The annual rate of injection, which peaked in 1990 at 7 million m3, has declined since then, due to increasing demand for treated wastewater. In 2005, the treatment plant was injecting from 35% to 50% of its production (Sheng, 2005). Drinking water quality standards have been maintained in the Hueco Bolson and the level of groundwater has been increased by about 5 meters near the center of the recharge well field. Raising the level of groundwater in the Hueco Bolson has been an additional goal of the recharge project.

Two Examples from Australia

The first aquifer storage and recovery program utilizing treated wastewater in Australia was established at the Bolivar sewage treatment plant near Adelaide in 1996 (Dillon et al., 2006). One goal of the program was to test the injection and recovery operation, using wastewater treated only to the quality required for unrestricted irrigation. The injected wastewater thus contained substantial nutrient concentrations. Between October 1999, and June 2002, 364 ML of water were injected into the aquifer and 243 ML (67%) were recovered (Dillon et al., 2006).

The estimated cost of the program, excluding the cost of water treatment and the pipeline, ranges from \$0.08 to \$0.18 per m^3 (Dillon et al., 2006). This range includes a portion of the farm-level cost range for pumping groundwater in the region, which is \$0.12 to \$0.34 per m^3. If the farm-level perception of the recovered water is positive, it should be possible to design a price structure that enables the City to recover its incremental costs of operating the aquifer storage and recovery program, by charging prices that farmers are willing to pay.

A second aquifer storage and recharge program utilizing treated wastewater was established in Alice Springs, Australia, following workshops with stakeholders that took place from 1998 through 2003 (Dillon et al., 2006). Infiltration was chosen as the method of recharge in the Alice Springs program, to avoid the more restrictive water quality guidelines pertaining to injection. Additional investigation is required in selecting a recharge site, however, as planners must consider the characteristics of both the aquifer and the overlying soils (Dillon et al., 2006).

Groundwater salinity should be reduced in both the Adelaide and Alice Springs programs, as the salinity of reclaimed wastewater is less than the salinity of typical groundwater withdrawals (Table 8). Reductions in groundwater salinity might improve the likelihood of charging a price for irrigation water that recovers a substantial portion of the aquifer storage and recovery program.

Table 8. Selected characteristics of the aquifer storage and recovery programs in Adelaide and Alice Springs, Australia

	Units	Adelaide	Alice Springs
Recharge method		Injection	Infiltration
Trial capacity	ML / year	250	600
Groundwater salinity (typical)	mg / L	2,100	1,900
Reclaimed water salinity (typical)	mg / L	1,200	1,000
Land area required	m^2	< 200	< 20,000
Notes:			
The aquifer in Adelaide is extensive, confined tertiary limestone.			
The aquifer in Alice Springs is unconfined alluvial paleo-channel.			
Source: Dillon et al., 2006.			

SUMMARY

The increasing use of desalinated water and treated wastewater for potable and non-potable uses will bring new challenges for farmers, water purveyors, and public officials in the years ahead. In many areas, new polices and programs will be needed to support the development of desalination and the treatment and wise use of wastewater. In arid regions with limited water supplies, treated wastewater is a resource that can expand the supply of water available for agricultural and landscape irrigation and other non-potable uses. Several countries also use treated wastewater in aquifer recovery and storage programs. Whether injecting wastewater into aquifers or infiltrating it through the soil, recharge programs enable timely use of treated wastewater, while also providing a helpful buffer between wastewater and the consumer.

Public preferences regarding wastewater and desalinated water have been examined in several countries. Citizens generally express health and aesthetic concerns regarding wastewater, while they have fewer concerns regarding desalinated water. Public education programs can enhance consumer acceptance of treated wastewater as a component of their water supply, particularly if the programs present supportive information based on sound science.

REFERENCES

Dillon, P., Pavelic, P., Toze, S., Rinck-Pfeiffer, S., Martin, R., Knapton, A., Pidsley, D., 2006. Role of aquifer storage in water reuse. *Desalination* 188 (1-3): 123-134.

Dolnicar, S., Hurlimann, A., 2010. Desalinated versus recycled water: what does the public think? *Sustainability Science and Engineering* 2: 375-388.

Fine, P., Halperin, R., Hadas, E., 2006. Economic considerations for wastewater upgrading alternatives: An Israeli test case. *Journal of Environmental Management* 78(2): 163-169.

Gikas, P., Angelakis, A.N., 2009. Water resources management in Crete and in the Aegean Islands, with emphasis on the utilization of non-conventional water sources. *Desalination* 248(1-3): 1049-1064.

Gikas, P., Tchobanoglous, G., 2009. Sustainable use of water in the Aegean Islands. *Journal of Environmental Management* 90(8): 2601-2611.

Hartley, T.W., 2006. Public perception and participation in water reuse. *Desalination* 187(1-3): 115-126.

Marks, J.S., 2006. Taking the public seriously: the case of potable and non potable reuse. *Desalination* 187(1-3): 137-147.

Sheng, Z., 2005. An aquifer storage and recovery system with reclaimed wastewater to preserve native groundwater resources in El Paso, Texas. *Journal of Environmental Management* 75(4): 367-377.

Van der Bruggen, B., 2010. The global water recycling situation. *Sustainable Science and Engineering* 2: 41-62.

WATER RESOURCES ECONOMICS AND PROJECT DEVELOPMENT — A CASE STUDY APPROACH

Rick L. Gold, P.E., D.WRE.[1]
David C. Auslam, Jr.[2]
Robert B. Hamilton[3]

ABSTRACT

This paper discusses the importance of water resource economics in the decision making process for the implementation of Federal Reclamation projects. It briefly describes the history of the development of the Principles and Guidelines (P&Gs). The paper delves into the two primary methods for achieving project authorization and funding; 1) Following the executive branch agency processes of study and application of P&Gs, and 2) Following the political path directly to Congress. The paper shares some candid perspectives about the two methods, the advantages of each method, and the ultimate role of the Office of Management and Budget (OMB) in establishing the administration's position regarding any proposed federal project. The paper explores case studies involving the two methods. The paper concludes with a brief examination of the ongoing US Army Corps of Engineers (USACE) and the President's Council on Environmental Quality (CEQ) review of the 1983 P&Gs with a look toward the future.

THE IMPORTANCE OF ECONOMIC ANALYSIS FOR PROJECT DEVELOPMENT

It is generally understood that federal government investment, particularly in major civil works infrastructure, was necessary for the United States to grow westward. Those expansion years saw many projects developed including transportation, energy, and water resources. The focus of this paper is on the investments made by the United States particularly in the water resource infrastructure of the West.

One might expect that before significant water resource development projects were undertaken there would be a great deal of analysis and study to help decision makers with the arduous task of committing the investor to the cost of development. Interestingly there does not appear to have been much attention paid to quantifying the economic benefits and costs of those early decisions until about the 1950s. Most of those decisions seem to be about providing the necessary water supply to broadly allow for the growth and economic stability of the West. Some might suggest that the same could be said of today's major investment decision making.

[1] Senior Consultant, CDM, 1886 South Wasatch Drive, Salt Lake City, UT 84108; goldrl@comcast.net
[2] Program Director, Senior Economist, CDM, 2295 Gateway Oaks, Sacramento, CA 95833; auslamdc@CDM.com
[3] Principal, Hamilton Economics, LLC, 1011 Meadow Run, Golden, CO 80403; hamecon1@msn.com

The Reclamation Act of 1902, upon which much of the western federal infrastructure is based, articulated the issue by simply stating that funding would be made available ". . . to be used in the examination and survey for and the construction and maintenance of irrigation works. . ." and then stating that ". . . the Secretary of the Interior shall determine whether or not said project is practicable and advisable . . ." If the Secretary makes such a determination "that any irrigation project is practicable, he may cause to be let contracts for the construction of same. . ." Of the repayment of those costs the Act goes on to say that water users would make annual installments, not exceeding ten years, ". . . with the view of returning to the reclamation fund the estimated cost of construction of the project. . ." While the ten year term was modified over time to as many as 40-50 years and the repayment burden was shared with municipal and power users the idea of returning the costs to the reclamation fund (albeit without interest in most cases) remained the principle. The Act uses the terms practicable and advisable to characterize the Secretary's decisions. The common definition of the word "practicable" includes: "that can be done or put into practice; feasible, or that can be used; usable; useful. The synonyms are possible or practical. The common definition of the word "advisable" includes: "to be advised or recommended; prudent and wise; fitting and sensible." There is not much about a B/C ratio greater than 1:1 in that!

To find the beginnings of today's more rigorous economic thought, we advance to about the 1920s when the idea of "welfare economics" is first introduced by Arthur C. Pigou. The idea is that the welfare of man, or a certain group or subset, could be measured and thus the impact that a particular action, like the construction of an irrigation project, would have on the welfare of the people could be determined. It was also recognized that all values could not be monetized. Some of the welfare of the people can be measured in terms of dollars of wages, income, crops produced, gross domestic product, etc. There are other measures of welfare that simply do not lend themselves easily to monetization. Some examples would be open space, scenic views, clean air, etc.

According to Henry P Caulfield, Jr. these ideas became a part of early Reclamation law in the 1936 Flood Control Act wherein it is stated that, ". . . it is the sense of Congress that . . . flood-control purposes are in the interest of the general welfare . . ." and that ". . . the Federal Government should improve or participate in the improvement of navigable waters . . . for flood-control purposes if the benefits . . . are in excess of the estimated costs. . ." It was from this modest beginning that the benefit and cost issues became more broadly utilized in the economic decision making for all water resource development, rather than simply focusing on the likely repayment ability of project beneficiaries.

By about the 1950s the first attempt to provide some guidance in this direction materialized. The Subcommittee on Benefits and Costs of the Federal Inter-Agency River Basin Committee produced the Green Book. The title of this book (with a green colored cover) was "Proposed Practices for Economic Analysis of River Basin Projects." When the Bureau of the Budget, now the Office of Management and Budget (OMB), in support of the Green Book concepts, then publish Circular A-47 with strict focus on making sure that benefits exceeded cost for any project, many in Congress became disenchanted with this strict test. In 1962 Senate Document 97 was published which set out a broader, compromise position. It was a multi-objective approach that provided for reasoned choices among development, preservation, and well being of the people. There was no requirement for benefits to exceed costs in Senate Document 97. However it did allow for the Bureau of the Budget to adopt such a standard for the administration. History would show that this need for a Benefit to Cost (B/C) ratio greater than 1:1 became the rule.

It was after passage of the Water Resources Planning Act of 1965 that the Water Resources Council began the preparation of the Principles, Standards, and Procedures. This process, through a number of iterations, has lead to the 1983 "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies" which are in place today. As you might know, or certainly expect, those 1983 Principles and Guidelines (P&Gs) are now being reviewed and revised.

TWO BASIC APPROACHES FOR FEDERAL AUTHORIZATION

Federal Authorization for Project Development

When the United States sets out to spend the people's money for water resources development projects it becomes a relatively complicated process. Under the separation of powers only Congress, the legislative branch of government, can spend (appropriate) money. The normal process for doing this, at least in water resource situations, is by Congress first passing a law (an authorization bill) to allow the expenditure of money for the purpose of the project; the President of the United States, in the Executive Branch, must sign that law before it is enacted. Congress then must appropriate the money to an agency in the Executive Branch by passing another law (an appropriations bill), the President must also sign this law before it is enacted, then the Executive Branch Agency is allocated the money from the US Treasury according to the appropriations law and can spend it for the purposes as provided in the authorization law. As subsequently addressed, the authorization and appropriations process applies both to funding of technical studies of the project and to funding for construction of the project if the studies conclude that it is justified.

Principles and Guidelines and Reclamation Transmittal to Congress

The 1965 Water Resources Planning Act established the Water Resources Council and directed the Council to "establish principles, standards, and procedures for Federal participants in the preparation of comprehensive, regional or river basin plans and for the formulation and evaluation of Federal water and related land resources projects." The Council first published the "Proposed Principles and Standards for Planning Water and Related Land Resources," along with a draft environmental statement, on December 21, 1971. After nearly two years of review and revision the Council established the "Principles and Standards for Planning Water and Related Land Resources" (P&Ss) and published the final environmental statement on September 10, 1973.

These 1973 P&Ss were quite clear in their intent which is stated as, "These Principles provide the basis for Federal participation with river basin commissions, States, and others in the preparation, formulation, evaluation, review, revision, and transmittal to the

Congress of plans for States, regions, and river basins; and for planning of Federal and federally assisted water and land resources programs and projects and Federal licensing activities as listed in the Standards." They go on to say that "Plans for the use of the Nation's water and land resources will be directed to improvements in the quality of life through contributions to the objectives of national economic development and environmental quality. . ." and that "planning for the use of water and land resources in terms of these objectives will aid in identifying alternative courses of action and will provide the type of information needed to improve the public decision making process."

The 1973 P&Ss run to 167 pages (the final environmental statement is 13 pages) and it is clearly stated that "a recommended plan must have net national economic development benefits . . ." (B/C ratio greater than 1:1).

On September 9, 1982, the Water Resources Council voted to repeal the 1973 P&Ss and to establish the "Principles and Guidelines" (P&Gs). Those 1983 P&Gs remain in place today. They run a total of 137 pages, continue much of the structure of the four accounts process of the P&Ss, but tend to soften the stance in a few areas by acknowledging that the full extent of the Water Resources Council and the River Basin Commissions does not now exist after funding was terminated during the Reagan administration.

The declared purpose of the 1983 P&Gs is "to ensure proper and consistent planning by Federal agencies in the formulation and evaluation of water and related land resources implementation studies." They declare that "A plan that reasonably maximizes net economic development benefits, consistent with the Federal objective, is to be formulated. This plan is to be identified as the NED plan (otherwise known as the National Economic Development Plan)." Related to selection of the recommended plan the 1983 P&Gs state that "The alternative plan with the greatest net economic benefit consistent with protecting the Nation's environment (the NED plan) is to be selected unless the Secretary . . . grants and exception. . ." The practical reality has been, however, that seldom if ever has an administration supported a project with less than 1:1 B/C ratio. OMB seemingly has paid an increasing amount of attention to project B/C ratios in determining whether to support funding for water resource projects.

Under Reclamation's (and other agencies covered by the P&Gs) processes a project sponsor will engage with Reclamation in some early planning activities. These are generally characterized as parts of a Geographically Defined Program, an Appraisal Study, or a Special Study. If the sponsor desires to move forward toward implementing a project then they and Reclamation must approach Congress to gain authorization to conduct a Feasibility Study. For Reclamation this requirement for Congressional authorization of feasibility studies originates in PL 89-72. If and when Congress authorizes a Feasibility Study for a specific project, then the study funding can be sought by Reclamation and appropriated by Congress. That Feasibility Study then must be performed in compliance with the 1983 P&Gs and that work must be incorporated into the appropriate National Environmental Policy Act (NEPA) compliance document based upon the proposed Federal Action. That combined document is then approved within Reclamation, forwarded to the Secretary of the Interior for review and approval, and submitted to OMB for approval. Only then can the document be submitted to Congress to seek authorization for construction. More than a few documents never complete this cycle. This is an arduous, time consuming, and costly process for project sponsors who are required to contribute 50% of the cost of this process. The success rate is dismal and many see the process as just too difficult. They choose another path.

The Political Path

This approach recognizes a fundamental principle of government. Congress does what Congress does. The United States Congress, as the legislative branch of government, passes the laws. If the subject of the legislation is so controversial as to elicit a veto from the President then some compromise with the executive branch is required. But passing legislation and packaging "veto proof bills" is the business of Congress. This alternate, political-path approach for many water resource project sponsors is to go straight to the Hill. They may choose to take any kind of documentation in support of their project prepared by their staff or a consultant. They may choose to take an appraisal study, special study, or even an environmental document prepared by Reclamation.

Once they convince their Congressman or Senator to introduce their bill to authorize construction of their project they are on the way. If their bill has some support the bill will likely get a hearing and, if invited, Reclamation or Interior will be a witness at that hearing. Testimony from the administration is drafted by the witness agency and must be approved by OMB. OMB gets the last word and the resulting testimony is usually crafted around the position that "the administration cannot support (or opposes) the bill." After the hearing, the Congress does what Congress does, and if the bill is passed out of the House and Senate it goes to the President for signature. If signed it becomes law and the project is authorized for construction (over the objection of the administrations testimony).

The projects sponsors typically go right back to Congress and seek a write in for appropriations to the agency to begin construction of the project. Given that they and Reclamation have complied with environmental law the agency usually begins construction. The one drawback from here on out is that the sponsor will likely have to seek a write-in for appropriations for all future years for the construction of the project, since it won't likely be included in the administration's budget request.

As you might see this process is a bit simpler and often easier than the agency/P&Gs approach. This is particularly the case for sponsors in states with strong Congressional delegations, with unified objectives regarding the potential project, and particularly when those Congressmen and Senators just happen to be high ranking committee members or chairmen. Most see it as an easier choice and take that approach.

The Imposing Role of the Office of Management and Budget

OMB plays a significant and powerful role throughout this process. OMB is organizationally located within the Executive Office of the President. It approves all Congressional testimony provided to the Hill on behalf of the water resource agencies. The decision on whether to support a bill or oppose it is theirs to make. Interestingly there are many occasions where senior officials in the water resource agency are in full support of the authorization of the project and yet the testimony they are required to deliver to the Congress (usually provided to them only hours before the hearing) clearly states that they are not in support or the project. Many struggle with the idea that within the executive branch of government there are two elements of the same administration which don't always seem to be on the same page. At times these positions are only finalized after a cabinet-level Secretary makes a visit to OMB, and even then, most of the time the OMB position prevails. It seems most often that if it costs money, OMB objects.

PROS AND CONS OF THE TWO PROCESSES

The two processes discussed above lead to the same end; A decision by the United States Government to authorize and hopefully build a water resource development project or not. A positive decision means moving ahead while a negative decision usually means rethinking the project and considering bringing back a re-worked project changed to overcome the most serious of the identified objections. The lack of a decision, whether caused by a too lengthy planning process, the lack of approvals by the agency or OMB, or the inability to fund the process, is even worse. Sponsors are left to labor on or fold the tent. Water resource sponsors seldom fold the tent!

Following the agency process of planning in accordance with the P&Gs would seem to be preferable. This process generally provides the best and most detailed information to decision makers; it entails working with the same agency staff that might ultimately be asked to construct the project; and it begins with the bottom up approach to dealing with the Federal Government. The downsides are that it takes a great deal of time, it costs significant amounts of money, and it ends up with OMB making the major decision for the agency.

Following the political path has its advantages. The time and cost involved in planning are dictated by what your delegation can support, you deal with your own elected officials, the potential for success is related to the power of your delegation, and Congress does what Congress does. The downsides are that the ability to convince your delegation may depend on how they view your project, the amount of information about your project may not be as robust as they expect, the ability to package your project in a veto-proof way may be difficult and time consuming, and you may be relegated to annual appropriation write-ins for the construction of your project.

SOME CANDID PERSPECTIVES

In the process of developing this paper one of the most interesting processes was that of trying to identify a good case study in which a proposed water resources development project went through the Reclamation planning process utilizing the P&Gs, was submitted to the Department, was forwarded to and approved by OMB, and then on to the Congress to authorize construction of the project. Initially nothing just jumped out as an example.

To expand the historic knowledge base an email query was sent to about a dozen Reclamation employees who, in the judgment of the authors, might know off-hand of an example or two. While certainly not a statistical survey there were more than a few respondents who concluded that in their memory, or their career, there had not been any such projects which would qualify as an example of how a federal authorization for construction should have been achieved. The only real potential example that was offered up was from the early 1980s, over 25 years ago!

This lack of an example of how the federal authorization process is designed to work is not to say that authorizations have not occurred. Many projects have been authorized and surely that trend will continue. With each session of Congress it seems that a few projects are authorized. The interesting conclusion is that almost assuredly those projects are being authorized without having been subject to rigorous application of the P&Gs.

While assuredly the number of proposed new Reclamation water resource development projects, as traditionally defined, is much smaller than it used to be it is also observed that the federal investment in water resources is certainly at a significant level and many would agree that the current level of spending is not adequate to meet all the needs. What seems to be happening is that the available funding is going in new directions.

Within the Reclamation budget are programs that have grown over time. Some of those programs do not include the rigorous application of P&Gs. That is not to say that no economic analysis is being applied. Cost effectiveness is an important concept being applied in a few cases. Under that theory the projects in the program compete against each other and then those with the best cost effectiveness are those which move forward to be constructed. Title II of the Colorado River Salinity Control Program is one such program where projects are evaluated based upon the cost of reducing the salinity in the Colorado River in dollars per ton of salt removed. In other cases proposed projects are ranked by panels of specialists based upon how well they meet certain criteria (not exclusively economic) like technical adequacy, cost sharing, environmental issues, local support, type of solution, etc. The Water 2025 Challenge Grant program utilized this approach to prioritize potential projects and award grants for water conservation projects. In the case of the Water Reuse Program (known as Title XVI) a separate and distinct set of guidelines were developed which when followed resulted in a potential project's feasibility study being deemed as meeting the requirements of a feasibility study under the Title XVI authorizing legislation. A complete P&Gs analysis is not required under those guidelines, and Reclamation's determination does not constitute a recommendation for authorization of construction. For the new Reclamation Rural Water Program, which may entail lower cost projects than traditional water resource projects, application of the P&Gs to appraisal and feasibility studies conducted under the program is required by the implementing regulations. It will be interesting to watch the progression of this Rural Water Program to see if project sponsors see this application of P&Gs as too burdensome and simply opt for the political path to project authorization and funding.

Some speculate that these "alternate" methods or tests are being applied somewhat in relation to how much money is at stake. For lower dollar projects a simple ranking of potential projects to meet the program goals seems sufficient. When more money is at stake then perhaps a cost effectiveness approach works. With even higher level investments perhaps a unique set of guidelines is required.

The point to be understood here is that the current official process of application of the P&Gs is not working because it is not being utilized. Project sponsors are seeking other pathways to achieve authorization for water resources projects and they are being successful, in spite of the lack of support from OMB.

CASE STUDIES

The Navajo-Gallup Water Supply Project (A P&Gs Approach)

While this proposed project is a bit unique and does not exactly fit with the expected P&Gs process (because the Administration did not support the authorization), the Planning Report complies with P&Gs and the project was authorized for construction. The combined Planning Report and Final Environmental Statement was published in July 2009 and as such is one of the most recent project documents produced by Reclamation. The Feasibility Study was authorized by Congress in December 1971 within P.L. 92-199 as the Gallup project. The project was authorized for construction in P.L. 111-11 on March 30, 2009.

The purpose of the project is "to provide long-term (year 2040) supply, treatment, and transmission of Municipal and Industrial (M&I) water to the Navajo Nation, the Jicarilla Apache Nation, and the City of Gallup, New Mexico." The project would divert a total of 37,764 acre-feet of water per year from the San Juan River (a tributary of the Colorado River). The construction cost of this project "is estimated to be $864,400,000 (Reclamation, April 2007 cost estimate . . .)." The benefit to cost ratio is 1.25. The levelized cost of project water to the user is estimated to be $7.57 per thousand gallons.

There are several unique characteristics of this project process and that could likely be said for any process dealing with a proposed water resource development project. In the present case, the authorization to conduct a feasibility study was achieved in 1971. The early planning years for the then-named Gallup-Navajo Project produced a feasibility study and environmental impact statement in the early 1980s. Much controversy then existed within the Navajo tribal government and the net result was that the proposed project was not supported. Additional planning was intermittent over the years as funded through Congressional write-ins. In the early 1990s a steering committee composed of the project sponsors was formed to refocus the effort toward achieving a water resource development project. In addition, during those years and continuing through the early 2000s, there was significant activity among the Navajo Nation and the State of New Mexico in working to craft an Indian water rights settlement that would resolve long standing claims by the Navajo Nation in New Mexico. In April 2005 the Navajo Nation and the State of New Mexico reached agreement on the settlement. That settlement included the construction of the now-named Navajo Gallup Water Supply Project as it was described in the March 2007 Planning Report/Draft Environmental Impact Statement. At the hearing on H.R. 1970 in July 2007 the Bureau of Reclamation presented the Administrations testimony on this bill saying in part ". . . the Administration opposes the costs and cannot support the legislation as written." Ultimately the Omnibus Public Land Management Act of 2009, P.L. 111-11, approved, ratified and confirmed the settlement and authorized construction of the Navajo-Gallup

Water Supply Project. The administration continued to provide the same negative wording in its testimony on both House and Senate bills as they were rolled up into the Omnibus bill, passed, and signed by the President.

While the processes have been ongoing for nearly 40 years to bring a reliable water supply to the Navajo Nation, the City of Gallup, and other project sponsors it appears that success will be found. The beginning of construction will now likely be determined by the availability of federal appropriation to begin this nearly $870 million project. The near 40 year process is not terribly unique. Like many other water projects this one has had many hurdles to clear. Its final success seems, like many others in recent times, to be keyed to it being a part of an Indian water rights settlement.

The Klamath Dam Removal Project (A Political Path Approach)

While the Navajo-Gallup project is keyed to a tribal solution, the Klamath Dam Removal Project is keyed to a broad array of interests including tribal, agriculture, fisheries, power, water quality, land ownership and recreation. In the Upper Klamath River Basin in Oregon, an extensive system of dams and hundreds of miles of canals were begun in 1906. Today, the Klamath Reclamation Project irrigates more than 200,000 acres in Oregon and California.

In addition, between 1917 and 1962, the California Oregon Power Company (now called PacifiCorp) licensed and built four hydroelectric dams — three in California, and one in Oregon — that today produce enough electricity for about 70,000 homes (170 megawatts). The dams cut off the path for migrating fish and the impoundments behind them breed parasites that kill young salmon and trout.

For decades suits and countersuits have been filed by competing parties; most recently centering on alleged violations of long held water rights and the federal Endangered Species Act. Protests, local and federal police, and stepped up lawsuits prevailed. Then in September, during the drought of 2002, low flows, warm water temperatures, and exploding populations of parasites killed as many a 64,000 fish in the Lower Klamath.

The salmon die-off convinced most of the warring parties to start talking toward settlement instead of suing and the Klamath Settlement Group was formed in 2005. In 2008, the talks produced a settlement essentially agreeing to remove the four dams from the river and reduce allocations for irrigation by about 25 percent. In order for this to work, PacifiCorp's dam removal liability needs to be limited and a dam decommissioning agent (most likely Interior) needs to accept overall project management and absolute liability. Studies commissioned by Non-Governmental Organizations (NGO's) estimated physical dam removal would cost about $97 million. The 2008 settlement estimates restoration costs at $1 billion over a 10-year period.

Subsequently, Interior commissioned a Special Study to estimate the potential liability of removal of the four hydroelectric dams. The study by Camp Dresser and McKee, Inc. (CDM) was completed in the summer of 2008 and estimated identifiable liabilities as high as $862 million, with probably more that are not quantifiable at this time.

Now the daunting process begins to obtain government approval and appropriations. Congress must authorize and fund the necessary studies to comply with federal and state environmental laws (such as the Endangered Species Act, Clean Water Act and state sediment control laws) and then dam removal itself.

Reclamation is currently sampling the sediment behind the dams for contaminants. Reclamation is also planning a study, which would comply with the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA), sometimes called a NEPA/CEQA-type study, which could lead to a determination by the Secretary of the Interior as to whether Klamath Dam Removal is or is not in the public interest. It is unlikely that P&G's will be used to the letter of the law in these analyses. It is more likely that if the dams are ever removed, it will be *authorized* and *appropriated* by an act of Congress based on a series of Special Studies and environmental investigations.

While the Klamath Dam Removal is a somewhat unique project it is but one of many, many cases where water resource development decisions are made without rigorous application of the P&Gs. Other oft-quoted examples include the Mni-Wiconi Project in South Dakota and the Velarde Ditch Project in New Mexico.

THE ONGOING P&G REVIEW PROCESS

It seems like an afterthought to address the ongoing review of the P&Gs after the above demonstration of the relative importance, or lack thereof, in the last few decades of Reclamation water resource development. It will however tend to cement the central theme of this paper.

The USACE embarked on a review of the 1983 P&Gs in response to the 2007 Water Resource Development Act (WRDA) (P.L. 110-114) in which they were directed by the Congress to review and provide revised P&Gs within two years. They produced new proposed P&Gs in September 2008 which were circulated for comment. Many comments were received and many were not particularly happy with the resultant proposal. One of the key changes was to propose that the threshold level for approval of projects would be a benefit to cost ratio of 1.5 or higher. Given the difficulty of most projects with achieving the old 1.0 ratio this seemed to be going in the wrong direction for many. It appeared that the OMB perspective was about to get even tougher.

In a somewhat strange approach, however, the Council of Environmental Quality (CEQ) on July 1, 2009, issued a new federal register notice indicating that they were restarting the P&G review process and asked for input on the original 1983 P&Gs. In that federal register notice CEQ "provides an opportunity for interested individuals and organizations to submit suggestions for revising the Principles and Guidelines." It appears that the issue is now within the Executive Office of the President (at CEQ) rather that at USACE. This new process has at the time of this writing apparently produced a new draft of the revised proposed P&Gs for review by the government agencies. This effort is obviously still a work in progress. Stay tuned.

A LOOK TO THE FUTURE

As for the future it seems quite clear to the authors. No matter what the outcome of the revision of the P&Gs they will likely be designed to limit federal spending to only the very best of the best water resource development projects which are calculated to return at least the costs if not more to the economy. From a purely federal budget perspective, it is hard to argue with that approach. Given the current fiscal situation, the national debt, and the long held traditions of OMB, it seems very unlikely that project sponsors will opt for the "official path" to project authorization. It seems almost a given that sponsors will seek the power and influence of their members of Congress and work the political system to get authorization bills introduced and passed that can be enacted without the serious objection of the President. Then those newly authorized projects will be funded though write-in funding to Reclamation, even though Congress and the Administration publically oppose earmarks (write-ins). Congress does what Congress does!

So is there a right or wrong to this picture? I suggest not. If you are the federal government with limited financial resources, you should want to restrict your investments to the best ones you can find. If you are a local sponsor, you want to get your project constructed and the federal government seems the only pocket deep enough to get that done. Where you stand depends on where you sit. Life goes on!

REFERENCES

Caulfield, Henry P, Jr. (March 2000) "Early Guidelines for Water Resources Evaluation" (PDF). Proceedings of the Universities Council on Water Resources, pp14-17. http://www.ucowr.siu.edu/updates/pdf/V116_A5.pdf.

Pigou, Arthur C., "The Economics of Welfare" 1932, London, MacMillan and Co. (synopsis from Library of Economics and Liberty) http://www.econlib.org/library/NPDBooks/Pigou/pgEWCover.html

U.S. Water Resources Council, "Principles and Standards for Planning Water and Related Land Resources," Federal Register, September 10, 1973.

U.S. Water Resources Council, "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies," March 10, 1983.

UTILIZING MULTIPLE FUNDING AVENUES TO DEVELOP NECESSARY INFRASTRUCTURE IN JAMES IRRIGATION DISTRICT

Joseph D. Hopkins, P.E.[1]
Brian E. Ehlers, P.E.[2]
John Mallyon[3]

ABSTRACT

Due to multiple impacts being placed on the James Irrigation District (District) water supply, a study was performed to understand if the District could sustain its current operations. It was determined that the practices could continue but it would require capitally intensive improvements to the Districts infrastructure. Planned improvements include the construction of recharge basins for sustainability, installation of up to 16 groundwater wells and pumps, basin construction, pipeline installation, and construction of flow control and pumping structures. The improvements were estimated to cost approximately $9,000,000; a cost too high for the District to fund on their own. Because of the urgency of the project, The District explored multiple opportunities to fund the project. This included applying for loans, applying for grants, raising water rates, and raising land assessments; all at the same time.

To obtain loan money the District applied for funds through Proposition 82, distributed by the Department of Water Resources (DWR). At this same time, the district pursued loans through local banks, which provided a challenge considering the unstable banking industry.

Many components of the project are proposed to be built using grant funding. First was a Challenge Grant as provided by United States Bureau of Reclamation's (USBR) Water 2025 program; providing $300,000. Next was the USBR Field Services program; providing $25,000. Approximately $50,000 was utilized from the DWR Local Groundwater Assistance Program. In addition to these funds, Recovery Act funding became available for drought relief, where the District could obtain roughly $1,500,000.

To generate further income the District approved a water rate increase. It was at this time when it became apparent that the Districts revenue source had become out of balance. The Land assessments were not enough to cover the operational overhead of the District. To rectify this issue, land assessments would need to be raised. This would require a proposition 218 election, which has been pursued. The intention of this paper is to discuss the multiple funding sources available to the District, how they were utilized, and problems that have been encountered.

---

[1] Associate Engineer, Provost and Pritchard Consulting Group, 2505 Alluvial Ave, Clovis, Ca, 93611; jhopkins@ppeng.com
[2] Principal Engineer, Provost and Pritchard Consulting Group, 2505 Alluvial Ave, Clovis, Ca; behlers@ppeng.com
[3] General Manager, James Irrigation District, P.O. Box 757, San Joaquin, Ca 93660; jmallyon@hughes.net

INTRODUCTION AND BACKGROUND

Background

The James Irrigation District (James ID, JID, or District) is located in western Fresno County in proximity to the cities of Mendota and San Joaquin. The District was organized in 1920 under the California Water Code. Currently the District consists of approximately 23,000 acres, and annually supplies roughly 80,000 AF of water. In a normal year the District would receive 45,000 AF in surface water from the Central Valley Project (CVP). Of this 45,000 AF of CVP water, 9,700 AF is developed from the Districts historic right to San Joaquin River water (defined as "Schedule 2" water). The remainder of the grower demand is met by the 59 groundwater wells and unpredictable water supplies from the Kings River by way of the Fresno Slough Bypass. Provided below is a map of the District (Figure 1). The yellow area of Figure 1 represents the boundary of the District, while the tan area represents to Eastside Well Field for which the District possesses groundwater rights.

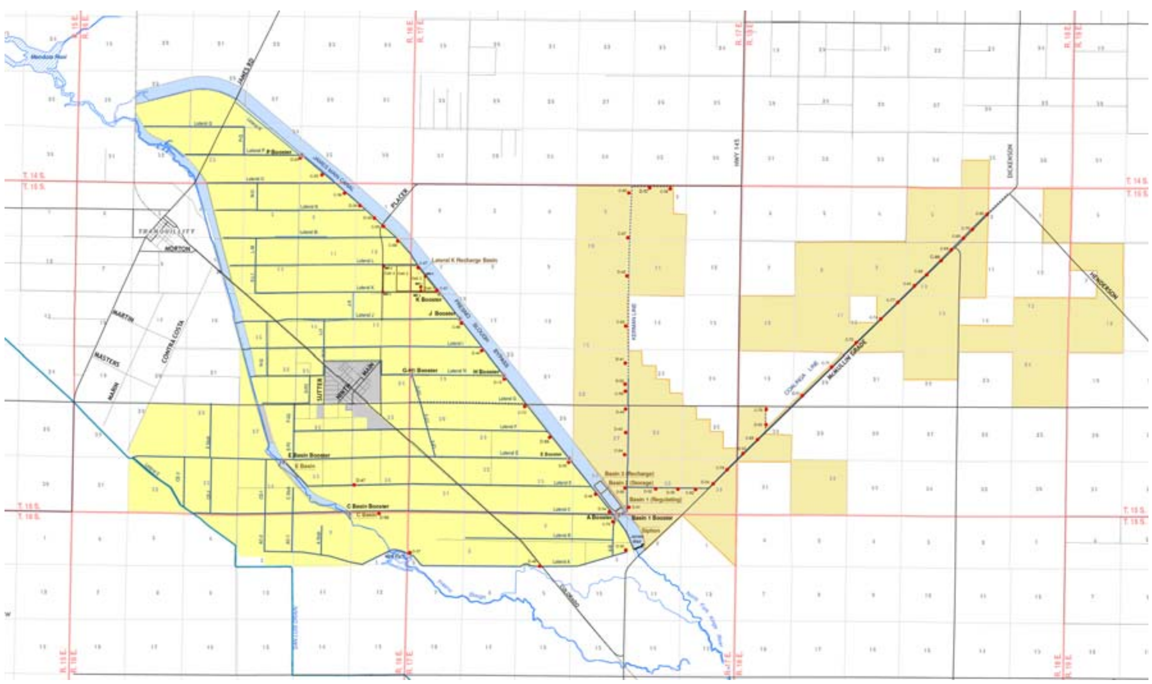


Figure 1. James Irrigation District Map

The CVP water supply is pumped from the Mendota Pool, which is adjacent to the eastern side of the northern quarter of the District. As the natural gradient of the District is south to north, the water received from the Mendota Pool must be pumped in reverse flow through the District's Main Canal to be delivered to the District's distribution system.

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

Purpose

Farming on the West side of the San Joaquin Valley is at a critical time. Due to drought and regulatory restrictions imposed upon pumping surface water from the Delta; the District as well as other CVP contractors south of the delta have seen 90% reductions in deliveries these past several years. This has led to significant financial hardships, land fallowing, severe unemployment and bankruptcy in some cases. To provide reliability and assurance to financial lending institutions, and recognizing that the regulatory climate was not going to change in the mean time, the District embarked upon an evaluation to determine if it would be possible to sustain their operations of providing agricultural water to users if the 35,300 AF of CVP water were not available.

The District has a contract for 9,700 AF of Schedule 2 water, and has 59 groundwater wells. It was determined that the District can acquire enough water from these two sources to sustain their practices, but cannot provide enough water to meet the instantaneous summer demand while maintaining the current level of grower flexibility. This is shown in Figure 2 below.

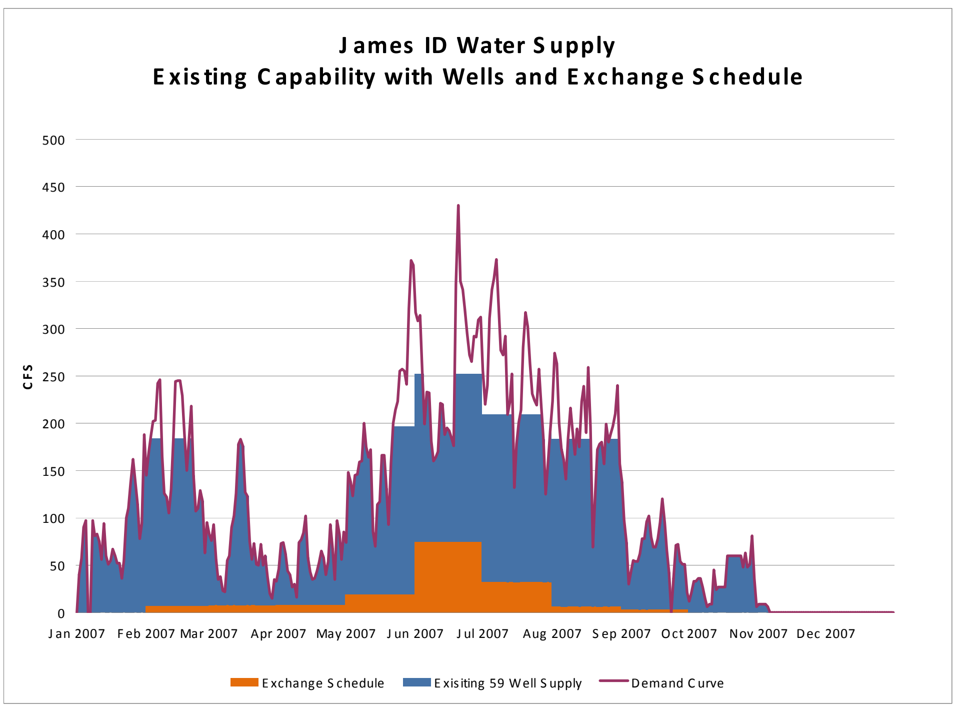


Figure 2. Graph Depicting Inability to meet Demand without CVP Supply

Project

To meet the needs of the growers in the unfortunate event of a zero CVP water supply the District has identified that there is the capability to provide complete delivery with the water resources available if the necessary infrastructure, as described in the follow paragraphs is developed. In summary, the project consists of developing intentional recharge area to recharge flood waters in wet years, storage basins are planned so that local storage can be provided to meet the short term peak system demands, and sixteen additional wells needed to provide the additional capacity of the lost CVP supplies. A majority of the improvements, including expanded intentional recharge facilities, will occur in the Fresno Slough Bypass. The multiple wells will be placed throughout the District. The proposed work was estimated to cost in excess of $9,000,000. Figure 3 shows how the proposed projects could replace a non-existent CVP Supply.

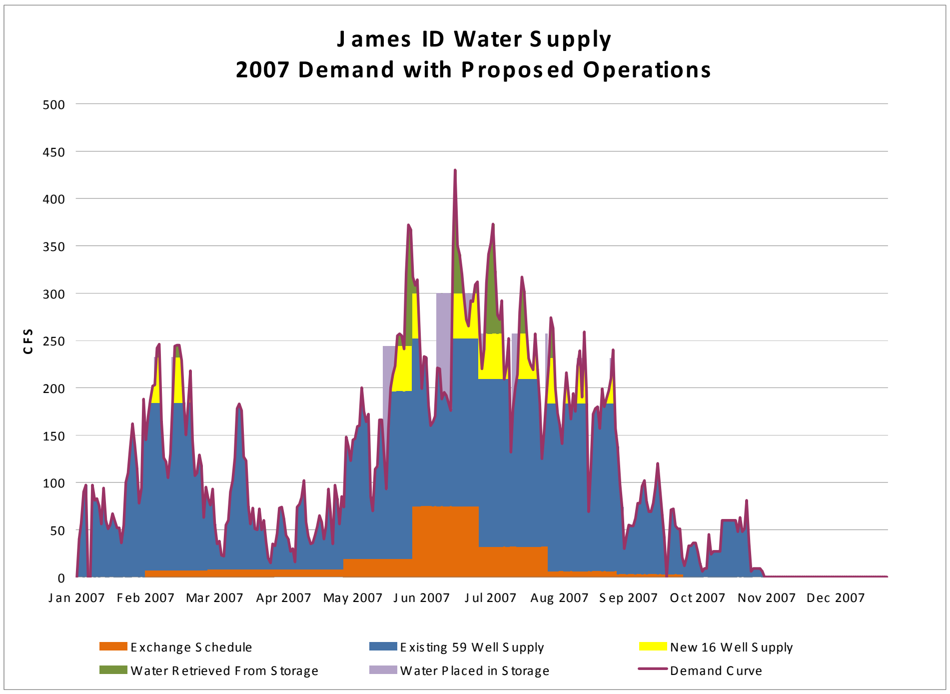


Figure 3. Future Operation of James Irrigation District

<u>Fresno Slough Bypass Basins</u> Figure 4 illustrates the proposed facilities of the Fresno Slough Bypass. An automated flow control device will be operated at the District's control structure, the E-Check Structure, where the ditchtender will have the ability of setting the flow rate to be maintained by the device. When there is excess flow from the Eastside Well Field, the gate will close and force water through the siphon and into the basins. Flow into the siphon will be regulated by level control. When the gate closes, the water level will rise and spill over a level regulation structure in the Main Canal. It is proposed that this structure consist of both ITRC Flap Gates and a weir section.

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

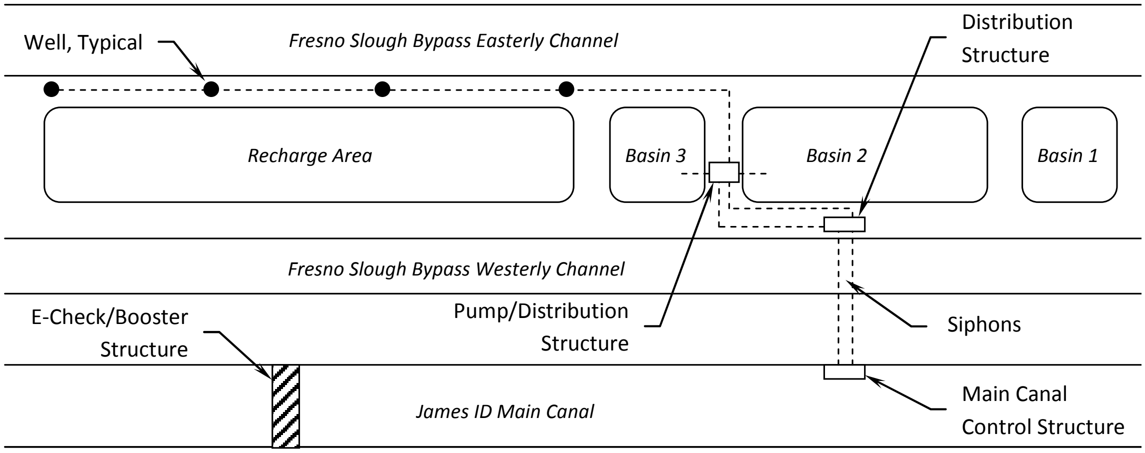


Figure 4. Proposed Fresno Slough Bypass Improvements

80 CFS total pumping capacity is proposed to retrieve water from these basins. Water will be conveyed from the pump stations into a separate pipeline and siphon that parallels the spill siphon and pipeline flowing toward the basins, and discharged into the Main Canal.

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

New Wells New Well construction was based on many considerations. These included system limitations, water quality, and site availability. Overall, four locations were determined for well locations; 1) four in the Eastside Well Field, 2) four west of Colorado Ave, 3) four at the K Basin Recharge Facility, and 4) four at the proposed recharge facility (Figure 5).

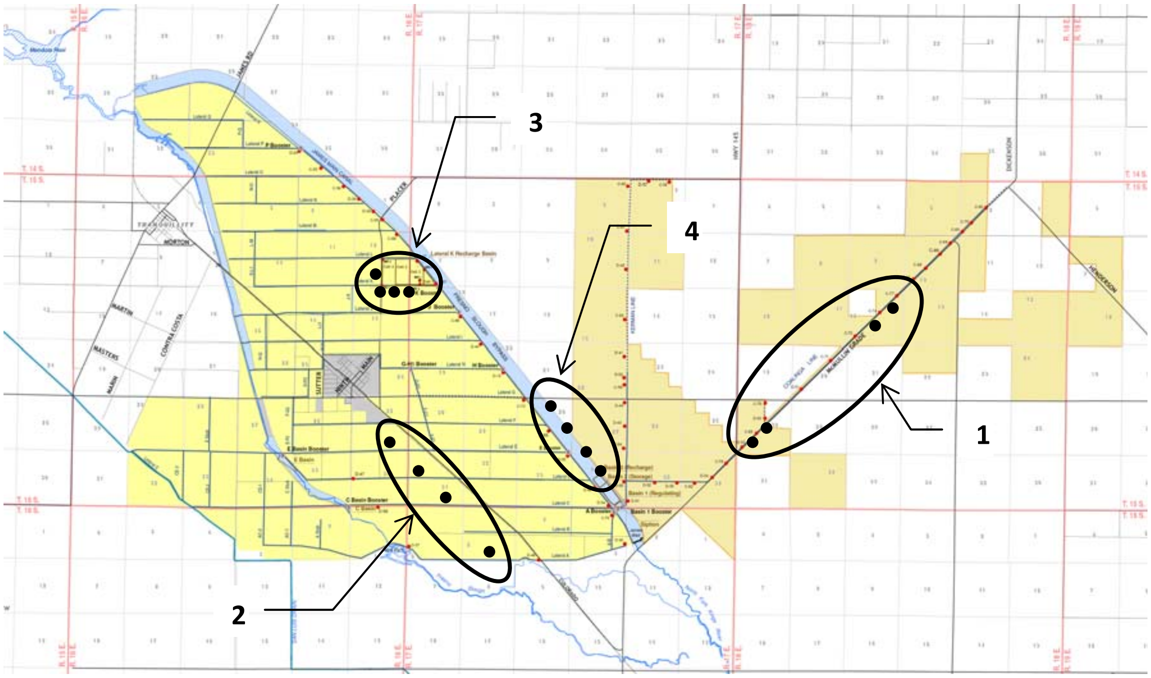


Figure 5. Proposed Well Locations

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

The area west of Colorado Avenue was chosen due to physical limitations of the existing distribution system. By placing wells here, more flexibility is provided to growers in this region.

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

FUNDING APPROACH

As stated previously, agriculture in the local area is at a critical juncture. No water, No business. However, it was determined the District can develop the resources needed, but could they pay for it? The estimated $9 million in capital cost relates to a cost of about $400/acre or about $800,000/year annualized. The increased energy cost and debt repayment were estimated to increase water costs by over $45/AF and there was concern that many growers could not afford his increase given the bleak financial climate. The District asked Provost and Pritchard Consulting group to find alternative methods to help fund the improvements.

With the drought conditions and other external issues impacting the water supply to James Irrigation District, The District is under pressure to get this project built quickly. The District required money immediately, so a “shotgun” approach has been taken to secure the needed funds; meaning multiple sources have been sought concurrently. These sources include grants, loans, volumetric water rate increase, and increased land assessments. Specifically, the programs and process listed below have been pursued.

- Proposition 82 Loan
- Water Conservation Field Services Program Grant
- ARRA Drought Relief Grant
- Water 2025 Challenge Grant
- Local Groundwater Assistance Grant (Assembly Bill 303)
- Proposition 218 Land Assessment Increase
- Volumetric Water Rate Increase
- Short-Term and Long term Financing

The District staff was too small to pursue funding on its own, and enlisted the help of Provost and Pritchard Consulting Group. Provost and Pritchard has enough capable staff to pursue these funding sources concurrently.

Proposition 82 Loan

The Proposition 82 loan is administered by the California Department of Water Resources (DWR). As part of the Water Conservation Bond Law passed by California voters in 1988, DWR is authorized to administer $20 million that provides construction and feasibility study loans to local public agencies for the development of local water supplies. A maximum of $5 million is available for each single construction project.The District has applied for funding through this program to fund the groundwater recovery facilities of the Water Augmentation Project. When originally applied for, the intent was to pay for the construction and equipping of wells on the Westside of the District, the equipping of wells at K-Basin Banking Facility, and the construction and equipping of wells in the Fresno Slough Bypass and the piping required to convey the water from the Fresno Slough Bypass to the District’s Main Canal. Receiving the money is not instantaneous, from application to approval the total elapsed time is 6 months. The District began the application in March 2009 and in October 2009 received notification that they were approved. However, due to budget problems in the State of California money was still not available. The money will be provided from bond sales by the State. The DWR has not been able to sell bonds for funding under this program as of yet.

Water Conservation Field Services Program

In 1997, USBR created the Water Conservation field Services Program (WCFSP). The WCFSP was created to: encourage water conservation; assist water agencies to develop and to implement effective water management and conservation plans; coordinate with state and other local conservation program efforts; and generally foster improved water management on a regional, statewide and watershed basis. The WCFSP provides grant money on a 50/50 basis. This means that the USBR will match each dollar the District provides until the funding ceiling is hit for that particular funding year. The funding cap for this had a maximum matching amount of $25,000. The District plans to apply this money to automating the Main Canal at the E-Check Structure. The application is fairly short and straightforward, and notification of award is rather quick. The District has had great success with this grant; being awarded in full the last five year, and for the current project described.

ARRA Drought Relief Funding

In response to the water shortages experienced by Westside farmers, the USBR offered money for immediate drought relief in May of 2009. This money would be used to produce water as soon as possible. The funding was part of the American Recovery and Reinvestment Act (ARRA) stimulus funding that was administer by USBR Mid Pacific Region, and more specifically the San Luis Delta Mendota Water Authority (SLDMWA). In total $40 million was made available through this program.

James ID submitted an application for four separate projects of the Water Augmentation Project.

- Lateral A Storage
- Basin Intertie
- K-Basin Well equipping
- West of Colorado Ave Wells and Pumps

Each project was proposed on the basis of being able to provide additional water to the CVP. Of the four projects submitted one was accepted; West of Colorado wells and pumps. This was also the most expensive. The amount of money awarded to the District was $1.51 Million.

This funding source was unexpected, but utilized to its full potential. The awarded project could now be removed from the Proposition 82 loan application, long term financing goals, and allow the proposed water rate and land assessment increases to be reduced. At over 10% of the project cost, this grant funding lowered the Districts future debt service considerably, but it is expected to take two years to get the money.

Water 2025 Challenge Grant

The Water 2025 concept began in 2003 as a way to prevent “crisis and conflict” in the west. Through the USBR, the water 2025 Challenge Grant provided up to $300,000 cost share for projects that conserve water. The highest ranking of these projects would be one that promoted water banks and water markets.

James ID applied for and was approved for this grant opportunity in spring 2008, to fund a portion of their Fresno Slough Bypass improvements. The District used its established banking program as its selling point. Specifically the program will provide funding for:

- Pump Structure
- Siphon
- Main Canal Control Structure
- Excavation of Basin 3

The water 2025 program has changed to Water for America, and then again to the Water Conservation Initiative. Typically it is available once a year, as a $300,000 cost share program. However, with the ARRA, in 2009 funding was available anywhere from $1,000,000 to $5,000,000.

DWR Local Groundwater Assistance Program

The Local Groundwater Management Assistance Act of 2000, aka Assembly Bill 303, was enacted to provide grants to local public agencies to conduct groundwater studies or to carry out groundwater monitoring and management activities. This program is administered by the Department of Water Resources. This grant provides up to $250,000, with no cost share required.

When this grant was originally applied for in the Winter of 2007, the plan was to conduct a water quality investigation of three distinct areas of the District. With the moratorium on funding distribution from California, the study was still taking place while the Water Augmentation Project began. The water quality investigation and the updated Groundwater Management Plan supported the goals of the Water Augmentation Project. The water quality investigation helped with the placement of wells, while the updated Groundwater Management Plan added support to the grant application, making them stronger candidates. Of the $248,000 awarded for the groundwater quality investigation, the District was able to use approximately $50,000 toward the Water Augmentation Project goals.

Priority for grant funding in this program is given to local public agencies that have adopted a groundwater management plan (GWMP) and demonstrate collaboration with other agencies in the management of the affected groundwater basin.

Proposition 218

While trying to implement the various projects of the Water Augmentation Project, it was determined by financial consultants that the Districts land assessments were lower than they should be. To enable the District to be marketable to prospective bond purchasers it is desired that all overhead cost be covered by the District's land assessments. This allows the District to function its necessary duties in absence of revenue generated by water rates. This is particularly important in years such as 2009, when CVP Allocation were only 10%.

Current District assessments have been $8.00/acre. This was proposed to be raised to $21.00; an increase of $13.00, or over 160%. With their current financial structure and existing debt service, it makes it difficult to obtain both short term and long term financing. By raising the rates, not only would the District be able to handle their current operating cost, but also have an additional $200,000 available that is not contingent upon water sales.

In order to raise assessments the District held an election under the Proposition 218 process. The District needed a majority vote from landowners to approve this assessment increase. The District began its pursuit of raising land assessments by first holding landowner information meetings. This was to inform District growers of the proposed project, the plan to provide water supply, and the resulting capability of the expanded distribution system. It also gave the District the chance to discuss various issues affecting the District, which are also felt by the growers, but the landowner themselves may not be informed of the problems. By aggressive outreach the District landowners voted by an 85.7% margin to vote yes on the assessment increase. An incredible feat given the economic condition of the time.

Water Rate Increase

The District had been actively installing infrastructure to ensure water supply for its growers. However, the District could not pay for all the improvements with only its general reserves. In addition, if the District were to spend most of their general reserves it would make it even more difficult to secure loan funding through a bank. The water rate increase not only helped to cover some of the future debt service of the Water Augmentation Project, but also allowed other needed repairs and improvements throughout the District; considering the District is nearing its 100 year anniversary.

Prior to raising the land assessments in the District, the District first raised their water rates. The water rate was increased by $15/AF, from $73/AF to $88/AF. This will generate an additional $750,000/year, assuming a normal year of water sales.

Short-Term and Long-Term Financing

In addition to all of the financing sources mentioned above, the District was still seeking financing through banking institutions. Their first goal was to secure roughly $1.5 million in short-term financing through a local bank. Short term financing will provide money to the District on a five year term without a prepayment penalty. This was required to keep moving on capital improvements until other funding comes through. It is also needed to prevent the District from dwindling their general reserves. A small general reserve will also make it more difficult for the District to gain their long term financing.

Long term financing will be provided by District bond sales. It is estimated that it will take 6 months to make this sale. However, with the permitting issues projected to last another year, the District will postpone the selling of bonds for another nine months. Once these funds are secured the District can pay off the short term loan mentioned above.

FUNDING SUMMARY

Currently the District has been pursuing different sources of funding since the Spring of 2008. The project is on track to be completed for the 2011 irrigation season. To date the District has generated roughly $2 million in grant funding. Also through fee increases, the District is set to receive approximately an additional $1.0 million annually. Table 1 below illustrates how the District will distribute the money gained to different facilities of the Water Augmentation Project.

Table 1. Distribution of Money to Water Augmentation Components

	Capital Facilities								
	Wells and Pumps				**Fresno Slough Bypass**				
Funding Program	West of Colorado	McMullin Grade	K-basin	Fresno Slough Bypass	E-Check Structure	Main Canal Control Structure	Siphons	Conveyance and Distribution Facilities	Excavation and Recharge Area Development
Proposition 82 Loan	X	X	X	X			X		
Water Conservation Field Services Program Grant					X				
ARRA Drought Relief Grant	X								
Water 2025 Challenge Grant						X	X	X	X
Local Groundwater Assistance Grant (Assembly Bill 303)	X								
Proposition 218 Land Assessment Increase		X	X	X	X	X	X	X	X
Volumetric Water Rate Increase		X	X	X	X	X	X	X	X
Short-Term and Long term Financing		X	X	X	X	X	X	X	X

It should be recognized that securing additional funding costs money. However, the cost is well worth the reward. Table 2 below illustrates the costs required to obtain the funding. As can be seen, the cost of pursuing funding is only a small percentage of the money available, and has been worth the investment.

Table 2. Cost of Pursuing Funds

Funding Source	**Funding Type**	**Cost**	**Funding Possible**	**Status of Award**
Prop 82	Loan	$20,000	$4,800,000	Pending
Water Conservation Field Services Program	Grant	$5,000	$25,000	Secured
ARRA Drought Relief	Grant	$5,000	$1,500,000	Secured
Water 2025 Challenge	Grant	$15,000	$300,000	Secured
Local Groundwater Assistance (Assembly Bill 303)	Grant	$20,000	$248,010	Secured
Proposition 218 Land Assessment Increase	Fee	$30,000	$200,000/year	Secured
Volumetric Water Rate Increase	Fee	N/A	$900,000/year	Secured
Short-Term and Long term Financing	Fee	N/A	$6,000,000	Pending

Grant funding is rarely guaranteed. The success of the Districts efforts can be attributed to utilization of an outside consulting firm, and the support material prepared over time that has enabled the District to take advantage of the multiple grant opportunities available. While it may seem like a nuisance, if any District is interested in getting grant funding, it is important to have good support material such as, Groundwater Management Plan, Water Management Plan, Feasibility Studies, and a banking program nexus.

COLLABORATIVE GOVERNANCE STRUCTURES FOR JOINT WATER RESOURCES PROJECTS

Kenneth A. Steele, P.E. [1]
Uli Kappus, P.E. [2]

ABSTRACT

The challenge of maintaining prosperity in the face of more limited fiscal, natural and environmental resources subscribes to the increased implementation of joint projects. Thus, joint projects are becoming more common for a wide range of water supply activities. At a mega-project level, the formation of entirely new special purpose organizations, such as a joint powers authority, may be merited. However, in today's world, the path to success may be found by organizations functioning in new ways rather than by forming new organizations to carry out joint projects in the traditional format.

The enabling mechanism for the joint project may have a title such as joint reservoir agreement, construction and operations and maintenance agreement or water conservation agreement. Such agreements are often established early in project development and endure for decades. Therefore, joint project agreements should contain governance provisions that address how project decisions are made and how disagreements among the participants can be promptly, efficiently and amicably resolved. The nature of these provisions must be tailored to the project and should vary according to circumstantial factors, such as which party is administering contracts, which party will own and maintain the improved facilities, how the project is being financed, how the benefits are to be provided and other relationships existing among the parties.

The governance provisions and functioning for five joint water resources projects are examined to illustrate their applicability for their respective situations. Involved are three joint reservoir agreements and two construction agreements for water conservation projects. The total cost of the five projects exceeds $1.4 billion.

INTRODUCTION AND BACKGROUND

The authors participated in the development of the Emergency Storage Project (ESP) for the San Diego County Water Authority (Water Authority) and helped develop principles of agreement and three joint reservoir agreements, adopted in 1995, that are instrumental to the success of that project. Two of these agreements are between the Water Authority and the City of San Diego (San Diego); the other is between the Water Authority and the Olivenhain Municipal Water District (OMWD).

[1] Consultant, 1740 Burnside Way, Stockton, CA 95207; kensteele@sbcglobal.net; Engineering Manager and Senior Program Advisor (retired) San Diego County Water Authority
[2] Vice President, Parsons Water & Infrastructure Inc; 1700 Broadway, Suite 900, Denver, CO 80290; uli.kappus@parsons.com

Later, in 2005, the authors participated, albeit in different roles and with different parties, in the All American Canal Lining Project (AACLP). The construction agreement for this project was largely based on the construction agreement for the Coachella Canal Lining Project (CCLP). These construction agreements are among the US Bureau of Reclamation (Reclamation), the Water Authority and the Imperial Irrigation District (IID) or the Coachella Valley Water District (CVWD), respectively. The construction agreement for the CCLP was developed and originally executed with Metropolitan Water District of Southern California (MWDSC). To facilitate larger agreements on the Colorado River, the Water Authority assumed the agreement for CCLP from the MWDSC. The construction agreement for the AACLP was largely drafted at the time the Water Authority assumed the MWDSC's responsibilities for the project. The IID and the Water Authority completed the negotiations and executed the final agreement directly. The provisions being specifically discussed in this paper are generally the same as had been developed between MWDSC and IID and vary only slightly from corresponding provisions in the construction agreement for the CCLP.

The five projects discussed in this paper have been or are currently being successfully executed. The projects have all experienced some significant challenges that could have derailed the project had not policy makers of the entities involved had faith in the provisions of the agreements and people carrying them out.

GENERAL DESCRIPTION OF PROJECTS

The Emergency Storage Projects

The purpose of the ESP is to protect the health, safety and economy of the greater San Diego Region from a prolonged severe interruption of imported water, such as could be caused by a great earthquake on the San Andreas Fault or a large earthquake on the Elsinore or San Jacinto Faults. Planning studies were began in earnest in 1992 following three unsuccessful attempts for reservoir development by three different water agencies in San Diego County during the 1980's. One of these attempts involved a cooperative reservoir agreement for a site to be developed by the Water Authority and which was owned by the San Diego for the location of a future reservoir.

The ESP consists of improvements at three reservoir sites, construction of five pumping stations, construction of about 20 miles of large diameter pipelines or tunnels, and development of recreation and environmental mitigation features. Construction was begun in 2000 and is scheduled for completion in 2012 with a total cost of over $1 billion

For the first increment of ESP storage, a new 318-foot tall roller compacted concrete dam is constructed at the Olivenhain Reservoir site. It is the largest roller compacted concrete dam constructed in the United States and was the first new roller compacted concrete dam permitted by the California Division of Safety of Dams (DSOD). Construction was begun in 2000 and completed in 2003. Through the joint reservoir agreement OMWD financially participated in the construction of the dam, owns capacity in the new reservoir, constructed a water treatment plant on the site, and manages the associated public recreation area. There is no direct yield from the Olivenhain site since it is located near the top of a watershed and not on a stream.

The existing Lake Hodges, constructed in 1918 and owned by San Diego, is re-operated to form the second ESP storage site. Additional usable storage capacity and significant additional local yield is obtained from the reservoir without increasing its size or modifying its dam. A new ESP pumping station and tunnel connect Lake Hodges with Olivenhain Reservoir and from there to the Water Authority's aqueducts and water treatment plant as well as San Diego's water treatment plants. The enhanced connection enables different operating rules for the reservoir. Through later planning and environmental studies, a 40 MW hydroelectric pumped storage project was added to this component of the ESP. Construction will be completed in 2010. Under the joint reservoir agreement the Water Authority obtains capacity in the reservoir and property for its pumping station; San Diego obtains the enhanced local yield. San Diego retains ownership of the dam and reservoir and the Water Authority participates in paying for their operations and maintenance costs. Lake Hodges has the largest watershed area of any of the 22 water supply reservoirs in San Diego County and, prior to the ESP, obtained water only from its watershed. Prior to the ESP, Lake Hodges was not connected to the aqueduct system for either supply or delivery; it had not been connected to San Diego's system since the 1960's.

The third ESP reservoir site is San Vicente. San Vicente Dam is a 220-foot tall concrete gravity dam that was constructed in 1945 and is owned by San Diego. The ESP raises the height of the existing dam by 54 feet using roller compacted concrete and provides new inlet and outlet works. This raise expands the capacity of the reservoir by almost 60 percent. Later planning and environmental studies documented the need for increased drought storage for the San Diego region. Through these studies, the dam raise was increased to 117 feet. This raise will increase reservoir capacity to about 270 percent of its current capacity. It will be the largest raise of an existing dam using roller compacted concrete in the world. Construction began in 2009 and is expected to be completed by 2012. San Vicente Reservoir contains a mixture of local water obtained from its watershed and from Lake Sutherland, also owned by the City of San Diego, and imported water from the Water Authority's First Aqueduct. Prior to the construction of the ESP it could deliver water to one San Diego water treatment plant but not back to the aqueduct system. The ESP also constructs a large capacity pipeline and pumping station to connect San Vicente to the Water Authority's Second Aqueduct. This is a much higher capacity aqueduct and following completion of the ESP, San Vicente Reservoir can both obtain and deliver water to this system of pipelines, and hence to other San Diego water treatment plants.

The Canal Lining Projects

The purpose of the canal lining projects is to conserve water for three primary purposes. One purpose is to correct a prior over allocation, by the Federal Government, of water from the San Luis Rey River in southern California. The other is to assist California water users in remaining within their allocation of water from the Colorado River without causing damage to agricultural or urban economies. The third purpose is to assist in resolving past inadvertent overuses of water for agriculture. California's annual allocation from the Colorado River totals about 4.4 million AF. About 3 million of this is allocated for the IID, about 1 million for other water agencies near the River, and about 400,000 AF by urban areas in coastal southern California. The All American and Coachella Canals account for deliveries of almost 80 percent of California's allocation.

Reclamation completed construction of the Coachella Canal in 1948. The canal extends for 123 miles from the All American Canal near the US border with Mexico to the Coachella Valley at the northern end of the Salton Sea. The northern 37 miles of the canal was lined during the original construction and the southern 49 miles was lined in 1982. The central section of the canal remained unlined and likely lost more than 30,000 AF of water per year to seepage and evaporation. The CCLP consists of approximately 36.5 miles of new lined canal, constructed immediately adjacent to the existing canal; 25 inverted siphon undercrossings of washes; one railroad undercrossing; and numerous environmental mitigation features such as deer fencing, wild animal drinkers, created desert marsh, and habitat improvements and set asides. The design capacity of the new lined canal is 1300 cfs. Flow was diverted into the new lined canal reaches in 2006; environmental enhancements are continuing. Project costs will total more than $120 million. The State of California provided funding of $83.65 million. Costs in excess of State funds are being paid by the Water Authority. Project agreements and Federal legislation provide the San Luis Rey settlement parties with 4550 AF per year of the conserved water. The Water Authority will receive about 21,500 AF per year. Additionally, some conserved water is used for environmental mitigation.

Reclamation completed construction of the All American Canal in 1942. It extends approximately 83 miles westward from the Colorado River at Imperial Dam into the Imperial Valley. The canal is adjacent and generally parallel to the US border with Mexico and is unlined. The AACLP includes about 23 miles of new lined canal constructed adjacent to the existing canal, a new vehicular bridge, a 1250 AF off-canal storage reservoir with instrumented gated inlets and outlet, a high capacity flow measurement flume, velocity measurement devices for low flows, canal maintenance roads, and numerous environmental mitigation features such as enhanced wetlands habit, desert dunes habitat, flat tailed horned lizard habitat and fishery enhancements. There are nine tie-ins to the existing canal at three hydroelectric drop structures, two interstate highway bridges, the beginning point and cross-over locations. Construction needed to take place with no interruption of flow in the canal. The new lined canal has a capacity of 10,155 cfs to Drop 1 and the head of the Coachella Canal, 7600 cfs to Drop 2 and 7400 cfs to Drop 3. The canal work was accomplished with two concurrent construction contracts. Work on one contract, involving Reaches 2 and 3, the off-canal reservoir, bridge and flow measurement features, was completed in early 2009. The other contract built Reach 1 and involved the excavation of over 22.5 million cubic yards of desert sand. Water cutover in Reach 1 occurred in mid-2009 and all work will be complete by early 2010. Total project cost will likely exceed $290 million. The State of California provided funding of $170.39 million. Costs in excess of state funds are being paid by the Water

Authority. The project will conserve about 67,700 AF of water annually with the San Luis Rey Settlement Parties receiving 11,850 AF and the Water Authority the balance.

OVERVIEW OF THE ENTITIES

Brief overviews of each of the local water agencies involved in the agreements discussed in this paper are given below. Agency characteristics are taken from their annual reports and other information published on their Web sites. In addition to the water sources mentioned in the overviews below, each of these agencies support aggressive programs for recycled water, conservation, brackish groundwater development and/or sea water desalination.

Coachella Valley Water District

The CVWD is located in southern California in the area generally east of the Peninsular Mountain Ranges and north of the Salton Sea. Its 1000 square mile service area is primarily located in Riverside County but contains some areas of Imperial and San Diego counties. It is governed by a five member board of directors who are elected. Annual deliveries by CVWD total 650,000 AF. About 459,000 AF of this is from its QSA allocation of Colorado River water; the remainder is from wells and the State Water Project, via exchanges. CVWD serves more than 102,000 customers and provides water for about 64,000 acres of irrigated crop land. The annual value of agricultural produce is typically about $550 million.

Imperial Irrigation District

The IID is the largest irrigation district in the nation. It is located in southern California in the area generally east of the Peninsular Mountain Ranges and south of the Salton Sea. IID provides water to approximately 145,000 customers including irrigation of about 450,000 acres of highly productive farmland. Over 97 percent of IID water is used for agricultural purposes. The annual value of agricultural production in its service area is typically about $1.3 billion. IID's supply is derived from its secured entitlement of 3.1 million AF of Colorado River water. IID is a public agency enabled by California state law and governed by a five member board of directors. Directors are elected by citizens of its service area.

San Diego County Water Authority

The Water Authority is located in coastal southern California west of the Peninsular Mountain Ranges. Its 24 member agencies (cities, irrigation districts, public utility districts, etc.) comprise over 95 percent of the population of San Diego County. The metropolitan San Diego region is the 17th largest in the nation with a population of 3.1 million. Total annual water use in the Water Authority's service area is about 690,000 AF of which the Water Authority supplies about 600,000 AF. The major economic sectors in the region are manufacturing, defense, tourism and agriculture. About 12 percent of water use is via agricultural water use programs established by the Water Authority or

MWDSC. Most Water Authority supplies are imported through two aqueducts from a delivery point in the MWDSC system. Most of this water is purchased from MWDSC, but some, like water from the canal lining projects, is separately obtained and transported through the MWDSC system to the delivery point. The Water Authority is governed by its 36 member Board of Directors; directors are appointed by the member agencies they represent. The Water Authority is a member agency of MWDSC.

Olivenhain Municipal Water District

The OMWD is located north of the City of San Diego between Interstate Highways 5 and 15. Its service area covers about 31,000 acres and has a population of about 56,000. Most of OMWD's 60,000 customers are homes and commercial businesses. Total annual water use is about 26,000 AF. OMWD estimates that about 10 percent of its water use is for agricultural purposes, but only 3 percent is enrolled in established agricultural use programs. OMWD obtains about 97 percent of its water from the Water Authority; the other 3 percent of its supply is reclaimed water. The OMWD is governed by a five member board of directors. Directors are elected by citizens of the geographic areas that they represent. The OMWD is a member agency of the Water Authority; its director on the Water Authority Board has a weighted vote of 2.68 percent of the total board vote..

City of San Diego

The City of San Diego is located west of the Peninsular Mountain Range in coastal southern California near the border with Mexico. It covers an area of about 210,700 acres and has a population of about 1.3 million. It is the seventh largest city in the nation. Total annual water use is about 240,000 AF; about 500 AF of this is for agricultural purposes. Typically about 83 percent of its supply is from the Water Authority, about 15 percent from local sources and about two percent is reclaimed water. Its local supply is predominately from its nine surface reservoirs. San Diego is governed by a mayor and eight city council members. The mayor is elected at large while the council members are elected by citizens of the geographic areas they represent. San Diego is a member agency of the Water Authority. Its 10 directors on the Water Authority Board must vote as a block and have a weighted vote of about 40 percent of the total board vote.

PRINCIPAL PROVISIONS OF THE VARIOUS PROJECT AGREEMENTS

The Emergency Storage Projects

The most pertinent provisions of the ESP agreements for Olivenhain Dam and San Vicente Dam are summarized below. The relevant provisions related to the ESP Lake Hodges Agreement are similar to those for San Vicente Dam.

Olivehain Dam Project:

The responsibilities and coordination procedures for design, construction, and operation and maintenance of the Olivenhain Dam project are addressed in the "Agreement

Between the San Diego County Water Authority and the Olivenhain Municipal Water District for the Emergency Storage Project (Joint Use of the Olivenhain Reservoir Site)" (Olivenhain JRA). Principles of agreement for the joint project were adopted by the boards of each agency in 1995 and the agreement itself in 1998. There have been several amendments to the agreement. The agreement provides for the joint use reservoir on site that had been obtained by OMWD. The Water Authority and OMWD had each separately completed CEQA documents for a 24,000 AF reservoir at the site. The Water Authority's document was a combined NEPA – CEQA document.

In general, the Olivenhain JRA provides that design, construction, and operation and maintenance of the dam, reservoir and an adjacent public recreation area would be jointly funded with each agency paying approximately in proportion to its share of reservoir capacity. The Water Authority would be responsible for the design and construction of the dam and reservoir. OMWD would have a price cap of $22.5 million and a minimum capacity in the reservoir. Except, that to the extent that costs exceed planning level cost estimated due to differing underground conditions, OMWD's cost share could be up to ten percent more or it could instead decrease its capacity by amount equivalent to its increased cost exposure. Each agency was separately responsible for the costs for their own planning and environmental studies. Any separate follow-on projects related to the joint reservoir must first be considered as a joint project with participation equal to each party's capacity in the joint reservoir.

The Water Authority would determine the ultimate design and configuration of the project in accordance with its environmental documentation. It was agreed that the project would honor and implement environmental mitigation commitments made by OMWD and that Olivenhain Reservoir would contain water from Lake Hodges. These two conditions were essential for each agency to have necessary support for a joint project. A combined operation with Lake Hodges was the only way that the Water Authority could justify environmentally, fiscally and practicably the reintroduction of the Olivenhain site into the candidate sites for the ESP. OMWD was particularly concerned about commitments made to nearby residents. It was agreed that OMWD could separately implement some of these commitments and its cost for doing so, up to agreed caps, would count towards its share of project costs. OMWD had completed all but a few of the required improvements for the public recreation site and some biological mitigation requirements. Its costs for these activities would be also credited toward its share of the project cost. Property ownership, for the dam, reservoir and recreation area would be transferred from OMWD to the Water Authority. Each agency would be responsible for its own separate projects (water treatment plant, pumping station, pipelines) in the vicinity and agreed to control their activities with regard to these projects so as not to interfere with each other or the joint reservoir project.

The Olivenhain JRA provides that the Water Authority would have lead responsibility for the design and construction of Olivenhain Dam and specified several requirements for coordination of these activities with OMWD. Among the requirements are:

For Design:

1. OMWD to have representation on the selection committee for the design consultant.
2. Water Authority and OMWD to each designate a representative responsible for coordination and review requirements including scheduling, preparation of plans and specifications, modifications to the dam and reservoir and site access.
3. Establishment of a Board of Senior Consultants (BOSC) to review project design products is required.
4. OMWD staff is provided the same frequency and time periods for intermediate design reviews as Water Authority staff through the sixty percent design and of final bidding documents.
5. OMWD is provided all copies of correspondence between Water Authority and its design consultant, DSOD and BOSC.
6. OMWD is provided the opportunity to attend all design review meetings, all meetings of the BOSC and all project meetings with DSOD.
7. OMWD mitigation measures are to be incorporated into the design.

For Construction:

1. OMWD is provided opportunity to review and comment on final construction contract bidding documents.
2. Water Authority contracting procedures, including resolution of protests, disputes and claims, are to be used for the construction contracts administered by the Water Authority and OMWD's for theirs.
3. OMWD afforded the opportunity to review and comment on change orders, 10 days if less than $500,000 or 30 days if greater. Water Authority may proceed if it determines a delay would cause unacceptable increase in cost or impact on safety.
4. OMWD to have representation on the selection committee for construction management consultants.
5. OMWD may designate a full time representative to be housed in the construction management office, provided by the Water Authority, during construction. OMWD is to independently fund the cost of such staff and their office provisions.
6. OMWD is afforded the opportunity to participate in all formal construction review meetings; all meetings, site visits and inspections by DSOD; review copies of correspondence between the Water Authority, its engineering consultants, its construction contractors and DSOD and participate in meetings of the BOSC.
7. Water Authority and OMWD representatives are to conduct periodic joint inspections of the work in progress and of the completed work.

Either party to the agreement may refer unresolved issues or unacceptable responses to comments to a dispute resolution panel provided for in the agreement.

<u>The San Vicente Dam Project:</u>

The responsibilities and coordination procedures for design, construction, and operation and maintenance of the San Vicente Dam project are addressed in the "Agreement Between the San Diego County Water Authority and the City of San Diego for the

Emergency Storage Project (Expansion of San Vicente Reservoir)" (San Vicente JRA). Principles of agreement for the joint project were adopted by the Water Authority Board and the San Diego City Council in 1995 and the agreement itself in 1998. There have been several clarifications or modifications of the agreement. The agreement provides for expansion and subsequent joint use of an existing water supply reservoir that is owned and operated by San Diego. Unlike the Olivehain site, San Diego had no near term plans or environmental documents related to the expansion or further development of the reservoir, except for a pumped storage project proposed by a private sector third party.

In general, the San Vicente JRA provides that the responsibility and costs for the design and construction of expansion of the dam and reservoir including relocation of San Diego's public recreation area and certain access road as well as all environmental mitigation costs will be borne by the Water Authority. The Water Authority will obtain a storage right in the expanded reservoir that is nominally the same as the increased capacity that the project creates. San Diego would have the same nominal storage capacity in the expanded reservoir as prior to the project.

The Water Authority, as part of the ESP, will also pay for the design and construction of a large diameter pipeline and pumping station connecting San Vicente Reservoir to the Water Authority's Second Aqueduct (and hence to San Diego's Miramar Water Treatment Plant). San Diego's yield from the San Vicente Reservoir would not be diminished and any additional yield developed by the project would belong to San Diego.

The new expanded dam and reservoir will remain the property of San Diego. San Diego will continue to have lead responsibility for the operation and maintenance of the expanded reservoir. Operation and maintenance costs would be shared by the parties in proportion to their share of capacity in the expanded reservoir. Opportunities for storage credits would be shared in proportion to capacity in the expanded reservoir. Costs and profits from the operation of the new public recreation facilities would belong to San Diego.

In general, future projects related to property ownership belong to San Diego. Future projects related to reservoir capacity or operations must first be considered as a joint project with the parties sharing costs and benefits in proportion to their capacity in the expanded reservoir. Except, the potential pumped storage project shall remain exclusively with San Diego and the Water Authority could expand the reservoir beyond the capacity needed for the ESP, at its expense, provided construction can begin by December 31, 2012.

The San Vicente JRA provides essentially the same requirements and opportunities for coordination, review and comment on design and construction as the Olivenhain JRA. Similarly either party may refer matters of disagreement related to the JRA, a dispute review panel established by the JRA.

The Canal Lining Projects

There are essentially four separate agreements governing each of the canal lining projects. These are:

1. The funding agreements for the projects with the California Department of Water Resources (DWR). These agreements were with IID for the AACLP and the Water Authority for the CCLP.
2. The financial arrangements agreements or understandings between the Water Authority and IID or CVWD. These agreements establish how the Water Authority provides project funding during lags, interruptions or insufficiency of DWR resources.
3. The “Allocation Agreement Among The United States of America, The Metropolitan Water District of Southern California, Coachella Valley Water District, Imperial Irrigation District, San Diego County Water Authority, The La Jolla, Pala, Pauma, Rincon and San Pasqual Bands of Mission Indians, The San Luis Rey River Indian Water Authority, The City of Escondido, and Vista Irrigation District.” The latter eight entities (those following the Water Authority in the title) comprise the San Luis Rey Settlement Parties. This is also the agreement that establishes how costs are shared for operations, maintenance and repair of the new lined canals.
4. The construction agreements among Reclamation, the Water Authority and CVWD or IID (Construction Agreement(s)).

Each of these agreements provide some form of dispute resolution. The specific provisions for a project “Coordinating Committee” (Committee) are contained in the Construction Agreements. The most pertinent provisions of the construction agreements for the canal lining projects are discussed below along with some of the differences in the agreements.

The Construction Agreements specify the obligations of Reclamation, the Water Authority, the Committee and IID or CVWD for each of the canal lining projects.

Some examples of duties and responsibilities of CVWD or IID are as follows:

1. Design and construct the projects in accordance with specifically listed Reclamation standards.
2. Develop project cost estimate, update quarterly and provide copies to the parties.
3. Prepare report of actual final project costs and provide to Reclamation and the Committee.
4. Continue operation, maintenance, repair and replacement functions of the canal during construction.
5. Provide for the management of all construction activities, which includes development of a written construction management plan, assure compliance with the environmental commitment plan, construction surveys, materials testing, construction inspections, safety, contract administration, documentation of construction by as-built drawings, and reporting regularly to the Committee.

6. Keep Reclamation and the Committee informed of construction activities through regular construction reports, Committee meetings, facsimiles or telephone calls.
7. Issue field change orders that are consistent with the scope of project specifications as approved by Reclamation. Promptly provide executed copies of change orders to Reclamation and the Committee.

Some examples of duties and responsibilities of the Water Authority are as follows:
1. Participate in Committee activities and use or make available its technical and administrative resources to assist in implementing the projects.
2. Prepare and submit estimates of its costs and itemized invoices of its internal costs to the Committee.

Some examples of differences in the canal lining agreements are as follows:
1. For the CCLP, the Water Authority submits invoices to DWR for reimbursements. IID performs this function for the AACLP. In both projects the Water Authority provides for coverage of lags in receipt of funds from DWR.
2. For the AACLP the construction agreement provided a mechanism where the Water Authority could eliminate or defer the construction of Reach 3 if projected project costs, as identified after bid opening, exceeded available DWR funding.
3. For the AACLP, the written construction management plan would need to be adopted by unanimous vote of the Committee. One important function of this provision was to align project contract change order authorities of the Committee and project staff with those provided to the Water Authority Board of Directors and its General Manager by its Administrative Code.
4. For the AACLP, the construction agreement provided clarifications for known or perceived changes in the project scope from that provided to the Water Authority in project descriptions, cost estimates, and environmental documents provided by Reclamation, MWDSC and IID. (Due to the advanced status of the CCLP and its Construction Agreement at the time that the Water Authority became involved, such matters would need to be handled by Committee vote and, if indicated, elevation through the dispute process.)
5. For the CCLP, the Coordinating Committee is to provide documentation and extent, if any, of loss of regulating storage to Reclamation as a result of the project in accordance with Section 203(b) of Title II.

The stated basic purpose of the Committee would be to provide a means of effective cooperation and interchange of information and providing consultations, reviews, recommendations and approvals on a prompt and orderly basis among the parties. The basic make up and functioning of the Committee is described in the next section. The Committee is responsible for providing actions, consultation, review and providing recommendations for approval by Reclamation on matters related to the design and construction of the canal lining project, some examples are:
1. Provide comments recommendations to CVWD or IID and Reclamation on draft construction plans and specifications within 15 days of receipt of the draft.
2. Documentation, accounting and approval of Eligible Project Costs.

3. Review and approval of schedules and updates of schedules for design and construction.
4. Documentation of and the extent of remedial measures required to protect public health and safety as a result of the project as related to Section 203(c)(3) of Title II and compliance with Reclamation's Safety and Health Standards.
5. Confirm that all work under a DWE has been satisfactorily completed and therefore qualified for payment.
6. Retention of consultants through IID or CVWD for the project.

The Canal Lining Construction Agreements provide for a dispute resolution process for disagreements by either the Water Authority or CVWD or IID with recommendations or actions of the Committee. A different dispute resolution process is prescribed for disagreements between Reclamation and other parties to the Construction Agreements.

ELEMENTS OF THE COORDINATION, DECISION MAKING AND DISPUTE RESOLUTION PROCESSES

The Canal Lining Projects

The basic mechanism for communication among the parties to the construction agreement for the canal lining projects is the Coordinating Committee. The Committee is comprised of three voting members, Reclamation and other invited interested entities. The three voting members are the CVWD for the CCLP, IID for the AACLP, the Water Authority and a third voting member mutually agreed by voting members of the Water Authority and IID for the AACLP and CVWD for the CCLP. The mutually agreed third voting member serves as chairman of the Committee. Reclamation is required to have a non-voting representative on the Committee. The Construction Agreements provide that DWR, the San Luis Rey Settlement Parties, Palo Verde Irrigation District and IID for the CCLP and CVWD for the AACLP shall be invited to have non-voting members on the Committee. DWR and the San Luis Rey Settlement Parties were usually present at regular meetings of the Committee. Other entities that were invited to have non-voting members and sometimes sent representatives to regular Committee meetings included California Department of Fish and Game, US Fish and Wildlife Service, US Bureau of Land Management and US Department of Homeland Security (Border Patrol). Project design, environmental and construction management consultants regularly meet with the Committee to provide project updated and status of their consulting contracts. Staff or special consultants often meet with the Committee to provide input to the Committee or assistance to their designated agency's representative in reviews.

The Construction Agreements provide that the Committee meets at the call of the Chairman and that either of the other two voting members could request the chairman to schedule a meeting. The Construction Agreement also requires that all Committee meetings be noticed fifteen days in advance, that the voting members be provided material related to potential Committee actions and that, to the extent practicable, the Committee is to be provided adequate time and information to fully evaluate and discuss any action or recommendation. The presence of two of the three voting members constitutes a quorum for the Committee. Committee decisions are made by majority vote.

In practice the Committees held regularly scheduled monthly meetings during most of the design and construction phases of both projects. The Committee often conducted special meetings, between the monthly meetings, involving primarily the voting members or the voting members and Reclamation and subject area support staff to consider financial or commercial matters, for design review workshops or to consider engineering or environmental issues.

The Construction Agreement provides the following process for resolution of disputes among the voting members of the Committee. The dispute resolution process can only be invoked by a voting member of the Committee. To initiate the dispute resolution process a voting member must send a written notice of such fact to the other voting members within 15 days after the subject of the dispute occurs or is brought to the attention of the Committee. The notice needs to set forth in detail the position of the member invoking the dispute resolution process. Within 30 days of such notice the general managers of CVWD or IID and the Water Authority shall have met and attempted to resolve the dispute to their mutual satisfaction. If they cannot, then within 60 days of receipt of initial notification, the general managers shall have each appointed one arbiter and notified the other voting members of the selection. The two arbiters thus named shall appoint a third arbiter within 30 days of the date that the last of them was appointed. The panel of three arbiters is to render a final decision of the dispute within 60 days after the appointment of the third arbiter.

In practice, with hundreds of decisions being made, the Coordinating Committee for the CCLP referred three matters to the general managers for resolution. In all cases the general managers were able to resolve the matters to their mutual satisfaction. Resolution took longer than the 30 days specified in the Construction Agreement. The managers mutually agreed to give themselves longer and to continue funding for the matters in question without prejudice. To date, the dispute resolution process has not been invoked in the AACLP.

The Emergency Storage Projects

The mechanism for coordination and communication between the agencies involved in the ESP project is provided by the appointment of representatives and requirements for review and communication that were previously described. If the designated representatives cannot reach an agreement on an aspect of the design, construction or operation and maintenance, either agency may invoke the dispute resolution process. The JRAs do not state who, from each of the parties may invoke the dispute resolution process. In practice the parties have issued letters designating such person, the general manager's designated representative to the project.

The JRAs designate a dispute resolution panel, for each project, as the first step in the dispute resolution process. The panels are composed of five members, one appointed by the Water Authority, one by San Diego (for the San Vicente Dam Project) or by OMWD for the Olivenhain Dam project, and three members mutually agreed to who are independent of both parties to the agreement. One of these three members is to be a professional engineer, another a certified public accountant, and the third a person experienced in the administration of water resources contracts. The three independent members are jointly contracted and paid by the parties to the JRA. The Water Authority representative serves as the chair of the panel during design and construction of each project and the representative of San Diego or OMWD becomes chair after completion of construction. (The panel for each JRA is independent and there is no requirement that the members be the same. They are described together here for brevity.)

The panels' mission is to provide a prompt and orderly resolution of disputes between the staffs of the Water Authority and San Diego or OMWD. The purview of the panels includes such matters as design and construction of the projects; documentation and review of O&M costs; seasonal storage credits; accounting of water in storage by each party; evaporative, seepage, leakage, spill and other water losses; and losses of recreational revenue at San Vicente. The panel has no authority regarding the award or administration of contracts by either party, or planning, permitting or environmental mitigation for the projects.

Either party to the JRA may submit a dispute to that panel. The submission must be in writing and detail the nature of the dispute and the requested resolution. The submission is to be to each panel member and the other party by certified mail or overnight delivery. The other party may submit a written response within ten days of receipt of the initial notice. The chair will provide notice to the parties and other panel members of a panel meeting to take place within 15 days of the receipt of the original notice. Panel meetings are intended to be informal and to facilitate open discussion of the dispute. The panel may request presentations from the parties. The panel is to reach a decision within 45 days of receipt of the initial submission of dispute. Panel decision is by majority vote. In the event that all members of the panel are not present, the chair will send a letter with the proposed action by certified mail, return receipt, to the absent member(s). If no response is received in 30 days, the action stands.

If the panel cannot reach a decision within the prescribed 45 days or the parties desire further review and resolution of the dispute, then the following actions are taken. The general managers for the parties have 15 days to decide if they may be able to personally resolve the matter. If so, then they will so notify the chair, who will schedule a meeting with the managers and the panel to take place within 21 days.

If one of the parties cannot accept the decision of the panel and the managers cannot determine that their personal involvement will resolve the matter then the dispute proceeds to arbitration. Within 55 days of the managers' determination that they cannot personally resolve the matter in dispute, each party shall select an arbitrator. Within 30 days of the selection of the last arbitrator, the two arbitrators shall select a third arbitrator. The arbitrators are to render a decision within 120 days.

The parties may appeal the decision of the arbitrators by filing an action in superior court within 60 days of receipt of the arbitrators' decision. The JRAs prescribe consequences for the filing of a court action without first going through an alternative dispute resolution process and for not prevailing in filing after following such process.

To date no matter has been referred to the dispute resolution process for the ESP. The panel for the Olivenhain Dam project has never met. The panel for San Vicente Dam will meet twice a year during construction and the first two years following construction. There have been a few matters on the Olivenhain Dam project that may have been candidates for the dispute resolution process. However, they have been or are being resolved by the managers or executive staff of the agencies. Some of these matters resulted in amendments to that JRA.

OBSERVATIONS AND CONCLUSIONS

Perceived risk to the project (as determined by the probability of something going amiss times the associated cost or importance of the consequences) enhances the need for closer day to day communications on the joint project. The actual or possible intervention by third parties is a project risk that enhances the needs of the parties for closer coordination.

Projects and their agreements can endure for decades but the people involved will change. Good governance processes, good documentation of project decisions and planned personnel transitions, whenever possible, are vital to maintaining harmony on the project.

Close communication and coordination during the design phase of a project helps develop a better common understanding of the project and fosters rapport between the parties prior to the more risky construction phase.

A mechanism such as the Committee used in the canal lining projects may help document agreements and clarifications as the project progresses or forces disagreements to light in a timely fashion to facilitate resolution.

A mechanism such as the panel used in the ESP projects may provide a way to elevate and resolve disputes and enable project staff to focus on the execution of the project. Top executives are not needlessly or prematurely directly engaged in the disagreement.

The establishment of time lines for resolution of disputes is important to facilitate the progress of the joint project and protect the interest of the parties. However, the parties may and should extend the time constraints, if doing so is or, can be made to be, mutually agreeable and could lead to resolution.

The agreement provisions for the panel in the ESP projects and the Committee for the canal lining projects both were modeled on the same source, a joint water conservation program by IID and MWDSC from the early 1990's. Just as the decision making and dispute resolution processes have adapted to the circumstances of the five projects, they would likely be further modified for future, even similar, projects carried out by the same entities. In developing governance provisions for a joint water resources project there is not likely to be an ideal precedent to simply copy. Rather one needs to understand the range of potentials available and circumstances in the various precedents considered.

DEDICATION

One of the challenges on both canal lining projects was the deaths of four key leaders of the project team (non Project related) within a period of six months in the year 2006. The authors, on behalf of the entire team of the All American Canal Lining Project and the Coachella Canal Lining Project dedicate this paper to their memory.

Kirk Dimmitt: Executive Program Manager for the both the AACLP and the CCLP. Kirk had been the lead for MWDSC for the Colorado River canal lining projects. He worked diligently more than a decade to bring these projects to fruition. Many consider him the father of the canal lining projects. He joined IID and continued his involved leadership in both projects following the transfer of the projects from MWDSC to the Water Authority.

Joe Summers: Chairman of the Coordinating Committees for the AALCP and the CCLP. Joe had also served as chairman of the committee for the IID – MWDSC conservation and water transfer program. The success of the committee for that program inspired the collaborative programs both for the future canal lining projects as well as the ESP.

Clyde Romney: Representative for the San Luis Rey Settlement Parties for both the AACLP and the CCLP. Clyde had long been the champion of the Native American Group along the San Luis Rey River for restoring their rights to its water. He served all those he represented as well as the project with dedication and effectiveness. His legislative efforts made the projects a reality.

James "Pat" Green: Environmental Manager for Reclamation for the AACLP and CCLP. Pat had been keenly involved in developing the Environmental Impact Statement for both projects and coordinating efforts under Federal and California laws. Pat was a key participant at almost every Coordinating Committee meeting. He gained the respect of every project leader as well as environmental resource agencies through his thorough knowledge of the environmental processes, documents and rules needed to keep the projects on track and successful. He upheld environmental values, worked with engineering and construction leads to find solutions when unexpected issues arose.

SYSTEM OPTIMIZATION REVIEW OF SHAFTER-WASCO IRRIGATION DISTRICT

Terry Nguyen[1]
Sam Schaefer[2]

ABSTRACT

As part of a larger system optimization review (SOR) that GEI Consultants, Bookman-Edmonston Division (GEI) conducted for the Poso Creek Integrated Regional Water Management Plan Region (Region), a portion of the budget was used to conduct a focused SOR to evaluate the Shafter-Wasco Irrigation District (SWID). GEI met with SWID's General Manager and System Operator with the goal to document their ideas on ways to improve the SWID system, prior to the retirement of the System Operator. The SOR assessed SWID's potential for managing their available water supplies more effectively and for improvements to their distribution facilities to maximize deliveries of neighboring districts' available surface water. The finding of the SOR documented internal and external opportunities for SWID to advance their current and future water management practices.

INTRODUCTION AND BACKGROUND

Shafter-Wasco Irrigation District (SWID), located in the southern portion of the San Joaquin Valley, California, receives Federal water from the Central Valley Project (CVP) via the Friant-Kern Canal (Figure 1). The District encompasses about 34,000 acres, of which about 30,000 acres are irrigated.

SWID's source of surface water supply is the Friant Division of the CVP, which develops its supply from the San Joaquin River, with storage provided by Millerton Lake. The water is transported to SWID through the Friant-Kern Canal. The surface water supply is used conjunctively with the underlying groundwater. SWID's contract entitlement consists of 50,000 acre-feet of Class 1 water and 39,600 acre-feet of Class 2 water, for a total of 89,600 acre-feet. The long-term average surface water supply available to the district is estimated at 69,000 acre-feet. The Class 1 water is storable (for use within a given year) and is considered a firm water supply. The Class 2 water supply is non-storable water and must be used when it is available.

The SWID system is a gravity system which delivers water using two turnouts from the Friant- Kern Canal. Water from the turnouts flows west supplying SWID's distribution systems called the "North" and "South" System (Figure 1). The two turnouts from the Friant- Kern Canal are located in North Kern Water Storage District. The northern turnout is the main line for the North System and the southern turnout is the main line for

[1] Staff Engineer, GEI Consultants, Inc., 101 North Brand Boulevard, Suite 1780, Glendale, CA 91203; Tnguyen@geiconsultants.com
[2] Senior Engineer, GEI Consultants, Inc. 5100 California Avenue, Suite 227, Bakersfield, CA, 93309; Sschaefer@geiconsultants.com

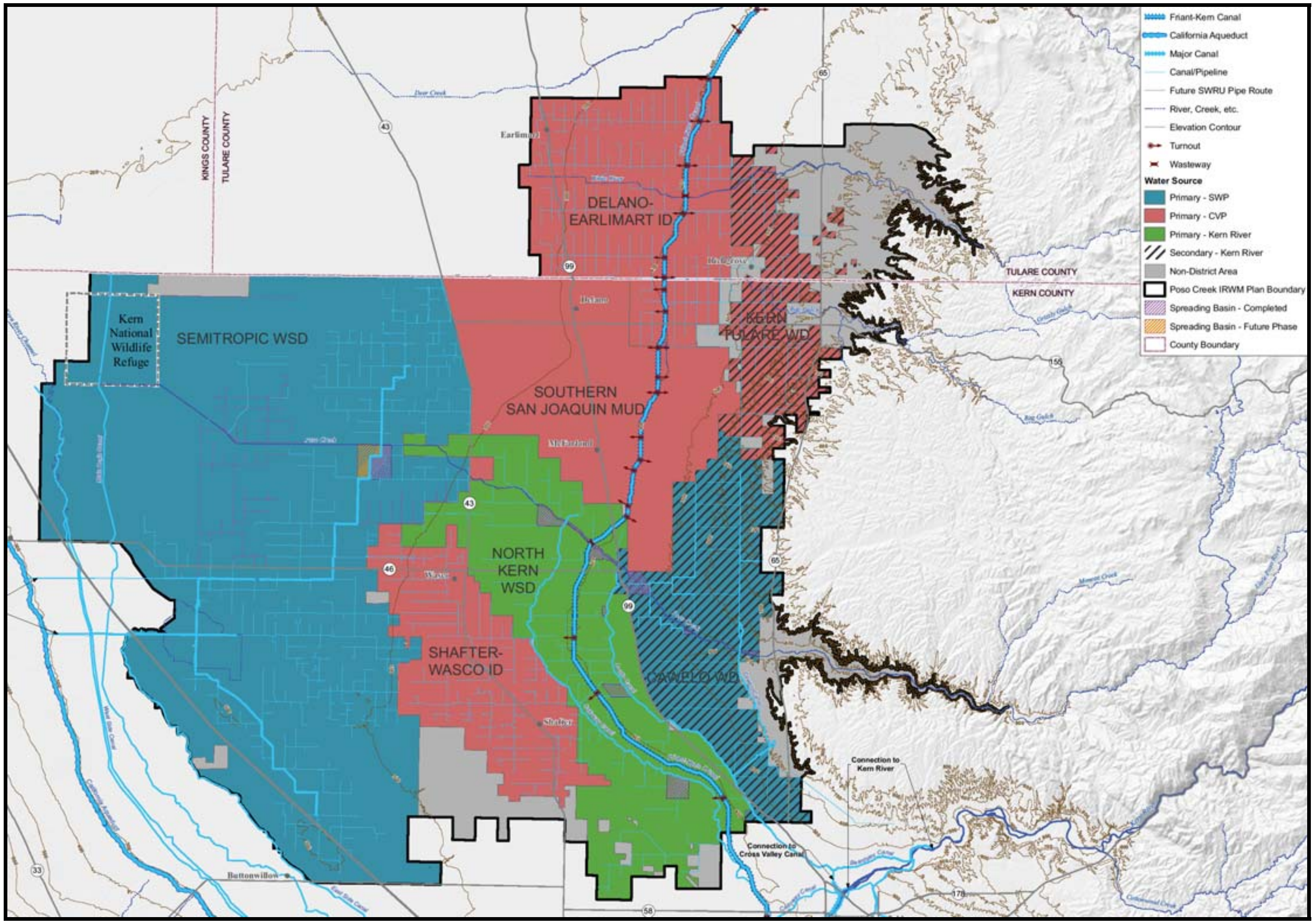


Figure 1. Shafter-Wasco Irrigation District and Neighboring Districts

the South System. Each turnout has a practical capacity of approximately 200 cfs.

SWID's primary purpose is to contract for the importation of water from the Friant Division of the CVP. It has the additional responsibility of conjunctively managing surface water and groundwater supplies to ensure an adequate water supply for water users.

As part of the system optimization review (SOR) specially conducted for Shafter-Wasco Irrigation District (SWID), GEI Consultants, Bookman-Edmonston Division (GEI), met with SWID's General Manager and System Operator to document their ideas on ways to improve the SWID system prior to the retirement of the System Operator. The SOR assessed SWID's potential for managing their available water supplies more effectively and for improvements to their distribution facilities to maximize deliveries of neighboring districts' available surface water.

Internally, SWID is addressing system modernization by adding isolation valves and replacing farm turnouts. The lack of isolation valves puts SWID and its users in a vulnerable position during times of maintenance or repairs. The old farm turnouts make delivery of water a time-consuming and hazardous task.

The SOR identified projects that would interconnect SWID with its neighboring districts (Semitropic Water Storage District and North Kern Water Storage District) for the purpose of increasing water banking and exchanges. The projects include:

- SWID/North Kern North Interconnection
- SWID/North Kern South Interconnection
- SWID/Semitropic Existing Interconnection
- SWID/Semitropic Madera Ave. Interconnection
- SWID/Semitropic Kimberlina Road Interconnection
- Multi-District Conveyance Facility

Previously in 2008, GEI completed an evaluation of the existing interconnection between SWID and Semitropic to identify any design modifications that would allow the interconnection to operate at a higher capacity. The findings included herein considered the details found in the 2008 evaluation.

OPERATIONAL ISSUES

<u>Isolation Valves</u>

A major issue with the SWID system is its lack of isolation valves along the pipeline main of its North and South Systems. Some of the existing valves on the main lines are worn-out and need to be replaced. Installation of additional isolation valves in strategic locations along the main line would minimize the number of users shut down during maintenance or repairs, allowing for a more reliable operation of the system. Ideal locations of new valves were not determined as part of the SOR. SWID will consider and evaluate new valve locations depending on known conditions, operational procedures, and budget. There are however, several valves along the main line of the North System that are known to be non-operational and need to be replaced.

Additional valves along certain laterals of the system would also help make the system more reliable. Existing valves are generally located at the beginning of each lateral. This allows for each lateral to be shut down independently of other laterals. However, some laterals can reach up to two miles in length; many laterals also have multiple sub-laterals. Maintenance or repairs along a lateral could potentially require shutting down the entire lateral. SWID will consider and evaluate ideal locations for additional valves as part of their long-term system improvements.

Farm Turnouts

Modernizing existing farm turnouts such as those shown in Figure 2 would allow for a more efficient operation. Currently, once an order for any specific amount of water has been placed, the system operator must open the turnout valve then climb up a ladder to read the water meter at the top of the turnout riser located inside the standpipe (Figure 3). To discharge the correct amount of water the operator must read the meter then adjust the valve accordingly, this guess-and-check procedure of calibration requires several iterations of climbing up and down the ladder to read the meter and adjust the valve. New farm turnouts, as shown in Figure 4 and Figure 5, have the turnout riser and water meter located outside the standpipe. With this configuration the operator can easily adjust the valve while reading the meter, greatly reducing the amount of time it takes to calibrate the turnout; this configuration also eliminates the hazard of climbing up and down a ladder.

Figure 2. Existing Farm Turnout Standpipe

Figure 3. Water Meter at Top of Turnout Riser Located within the Standpipe

Figure 4. Turnout Riser Located Outside of the Standpipe with Easily Accessible Meter

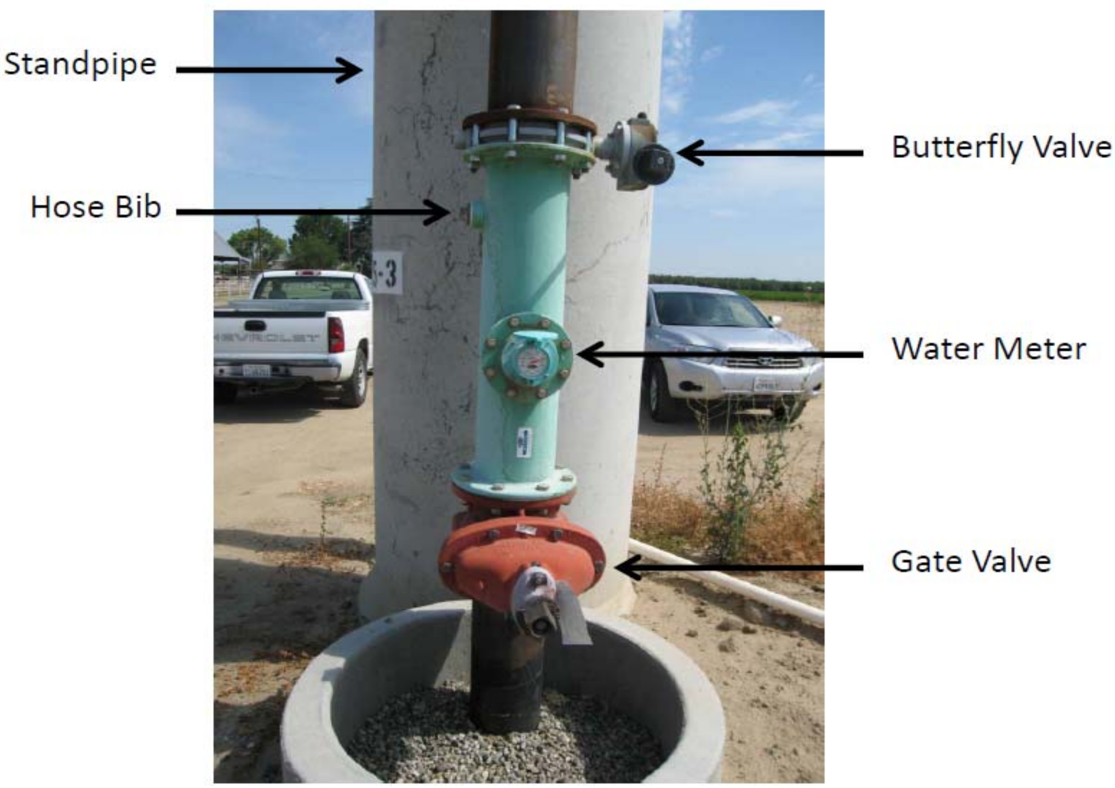


Figure 5. Modernized Farm Turnout with Gate Valve, Water Meter, Hose Bib, and Butterfly Valve

Old turnouts are slowly being phased out as the District began replacing and modernizing turnouts starting in 2006. Turnouts that have priority for replacement are ones that are leaky due to worn-out valves and ones that have high standpipe heights. The cost of replacing the turnouts is about $10-$12K per turnout. SWID will continue to replace turnouts as funding allows.

Findings and Recommendations for Modernization

With local funding, the District's priority is to continue to replace and modernize existing farm turnouts and add isolation valves. The District will evaluate grant programs to help fund system modernization; including Reclamation's grant programs that pay up to 50-percent for water saving and system efficiency measures.

EVALUATION OF EXISTING AND FUTURE CONVEYANCE BETWEEN DISTRICTS

Table 1 shows projects which are either existing, under construction, or proposed, that involve the interconnection of SWID with neighboring districts. Each project would allow for water exchanges between districts, increasing flexibility to SWID's system.

Table 1. SWID Interconnections

Project	Size	East-West Capacity (Gravity)	West-East Capacity (Pumping)	Project Status
SWID/North Kern North Interconnection	60" Connection Facilities	100 cfs	75 cfs	Under Construction
SWID/North Kern South Interconnection	48" Pipeline	50 cfs	50 cfs	Ready for Construction
SWID/Semitropic Existing Interconnection	36" Pipeline	>25 cfs	25 cfs	Existing
SWID/Semitropic Madera Ave. Interconnection	36" Pipeline	50 cfs	50 cfs	Planning/Preliminary Design
SWID/Semitropic Kimberlina Road Interconnection	60" Pipeline	75 cfs	75 cfs	Planning/Preliminary Design
Multi-District Conveyance Facility	84" Pipeline / New Canal	300 cfs	300 cfs	Planning/Preliminary Design

SWID/North Kern North Interconnection

A project nearing completion is the North Interconnection between SWID and North Kern that connects North Kern's Calloway Canal to SWID's North System (Lateral 134.4) (See Figure 6). The connection consists of approximately 180 ft of 48-inch diameter pipe and 120 ft of 24-inch diameter pipe, both with a pumped capacity of 75 cfs. The connection allows bi-directional delivery of water between SWID and North Kern.

In a wet year, when there are surplus supplies available off of the Friant-Kern Canal, the facility would be run in a mode of delivery into the Calloway Canal. From there, supplies can be delivered to the North Kern's direct and in-lieu recharge facilities. Also, in a wet year, if there are any supplies available to North Kern that may be delivered to USBR designated excess lands, this facility is a means of moving such water into Shafter Wasco's north system. In a dry year, the facility may be used to deliver North Kern deepwell produced water to SWID. Deliveries would be made either in return of a prior year Shafter-Wasco banked supply or for North Kern to delivery off-peak season water in exchange for peak season water for energy and supply management purposes. This project is currently under construction at an estimated cost of $650,400.

SWID/North Kern South Interconnection

Another interconnection project between North Kern and SWID is the South Interconnection that would connect North Kern's 8-5 ditch to SWID's South System (Lateral 137.2) via a 50cfs pipeline.

This project would allow Kern-Tulare Water District to convey its Kern River Water through the Calloway Canal and deliver it to SWID. In exchange, SWID's Friant water can then be delivered to Kern-Tulare. Without the project, Kern-Tulare delivers its 23,000 acre-feet per year of Kern River through an exchange with Arvin-Edison. This exchanged incurs a 20% loss to Kern-Tulare. Completion of the project will allow Kern-Tulare to exchange water with SWID and reduce losses to Kern-Tulare by 4,600 acre-feet per year. At this time, SWID cannot deliver its CVP water to lands within its service area designated as Excess under Reclamation Law. Therefore, this demand of approximately 15,000 acre-feet must be pumped from the groundwater basin. Once the project is completed, SWID will be able to take delivery of Kern River Water and banked groundwater directly from North Kern. The short term benefit of delivering non-CVP water in-lieu of pumping groundwater is the savings in energy charges. In the long term, the project saves groundwater for use in dry years and helps to off-set for regional groundwater overdraft which has been exasperated by San Joaquin River settlement. This project would also allow North Kern to deliver water stored in its groundwater directly to SWID. In exchange, SWID's Friant water can then be delivered directly to any CVP Contractor along the Friant-Kern or Madera Canal. This project significantly enhances North Kern's ability to complete exchanges of surface water supplies.

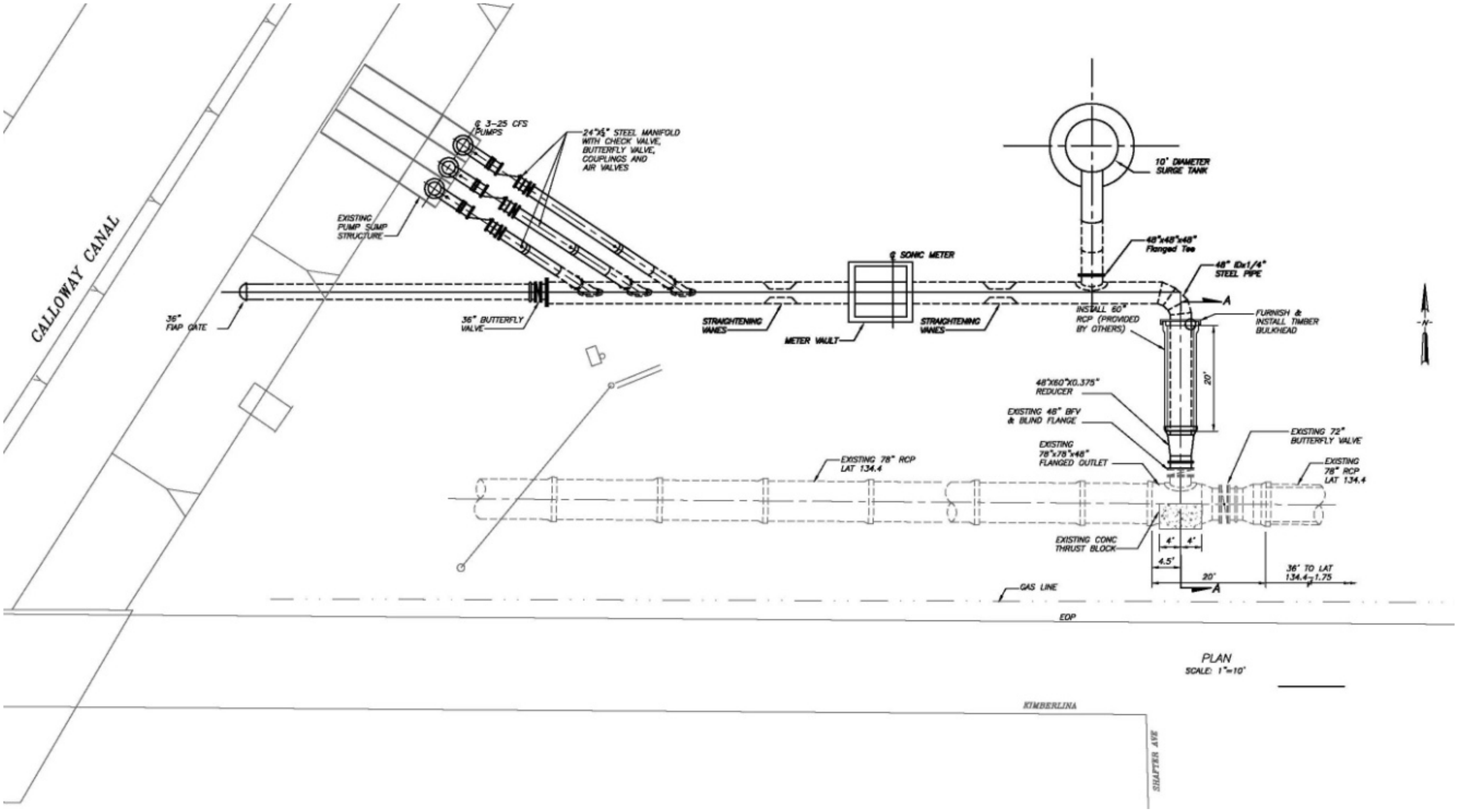


Figure 6. North Interconnection Between North Kern’s Calloway Canal and Shafter-Wasco’s North System (Lateral 134.4)

The South Interconnection between SWID and North Kern is ready for construction and is estimated to cost $600,000 to construct.

SWID/Semitropic Existing Interconnection

As mentioned earlier, the existing interconnection between SWID and Semitropic was previously evaluated in 2008 to identify any modifications that could be made to allow the Interconnection to operate at a higher capacity. Operation of the Interconnection in the west-to-east direction has proven to be challenging. The existing facilities consist of a pumping plant with a capacity of 625 horsepower and 25 cfs located at Semitropic's Pond-Poso Canal, and approximately 3.5 miles of 36-inch diameter pipeline that runs east connecting the pumping plant to the end of SWID's North System (See Figure 7 & 8).

As stated in the 1993 General Design Memorandum, operating parameters of and for the Interconnection in the west-to-east mode should be developed from exploratory operating experience after initiation of operations; for the operational conditions which result from introducing pumped Interconnection water (from the pumping plant located at the Pond Poso Canal) into SWID's system with isolation valves No. 2 and No. 3 open and CVP water flowing from the Friant-Kern Canal could not be completely predictable.

Along with several minor design changes and additions to the facilities, it was concluded from the 2008 study that in order for the system to operate more smoothly, changes to the operation of the Interconnection would need to meet mutually acceptable criteria from both the SWID and Semitropic operators. Communication protocols for operation of the Interconnection should be put in place and followed by both districts.

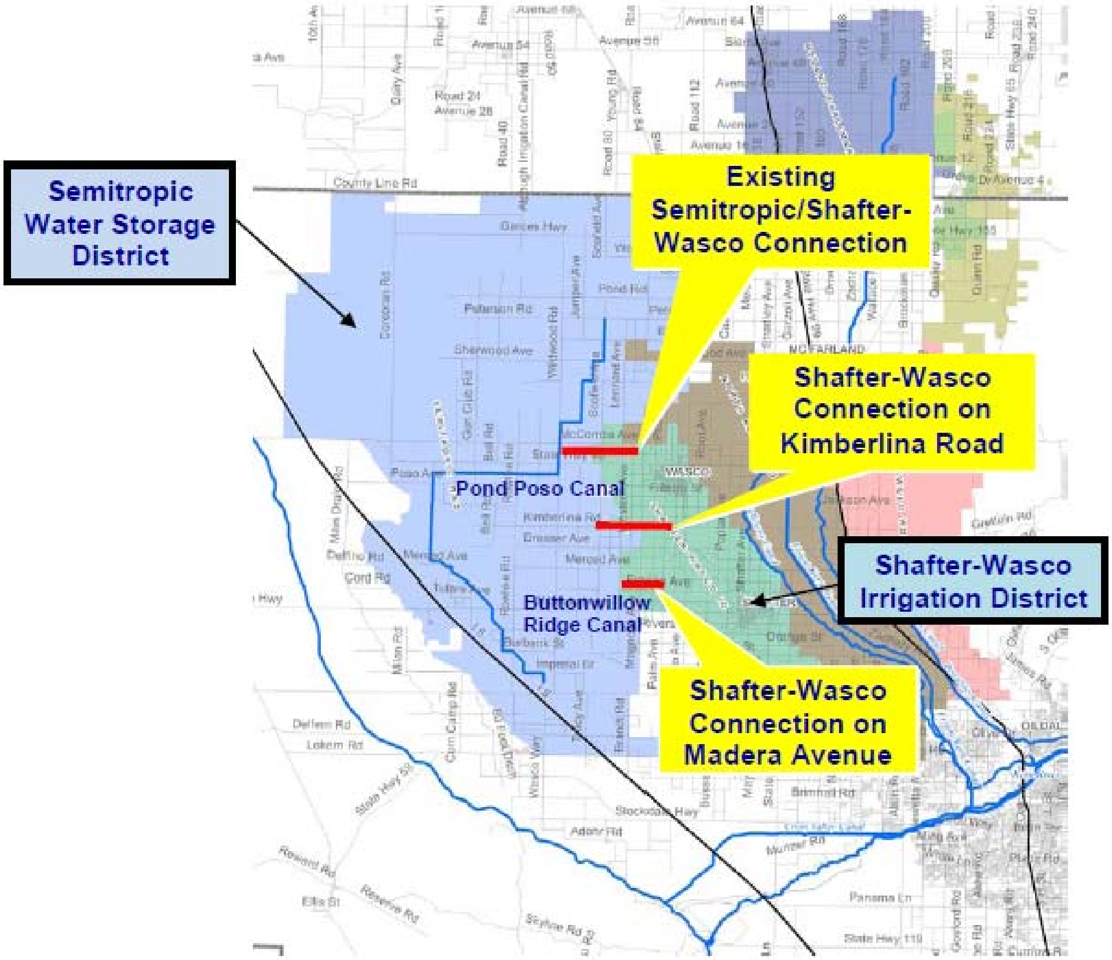


Figure 7. Semitropic Water Storage District and Shafter-Wasco Irrigation District with Locations of the Existing Interconnection, Kimberlina Road Interconnection, and Madera Avenue Interconnection

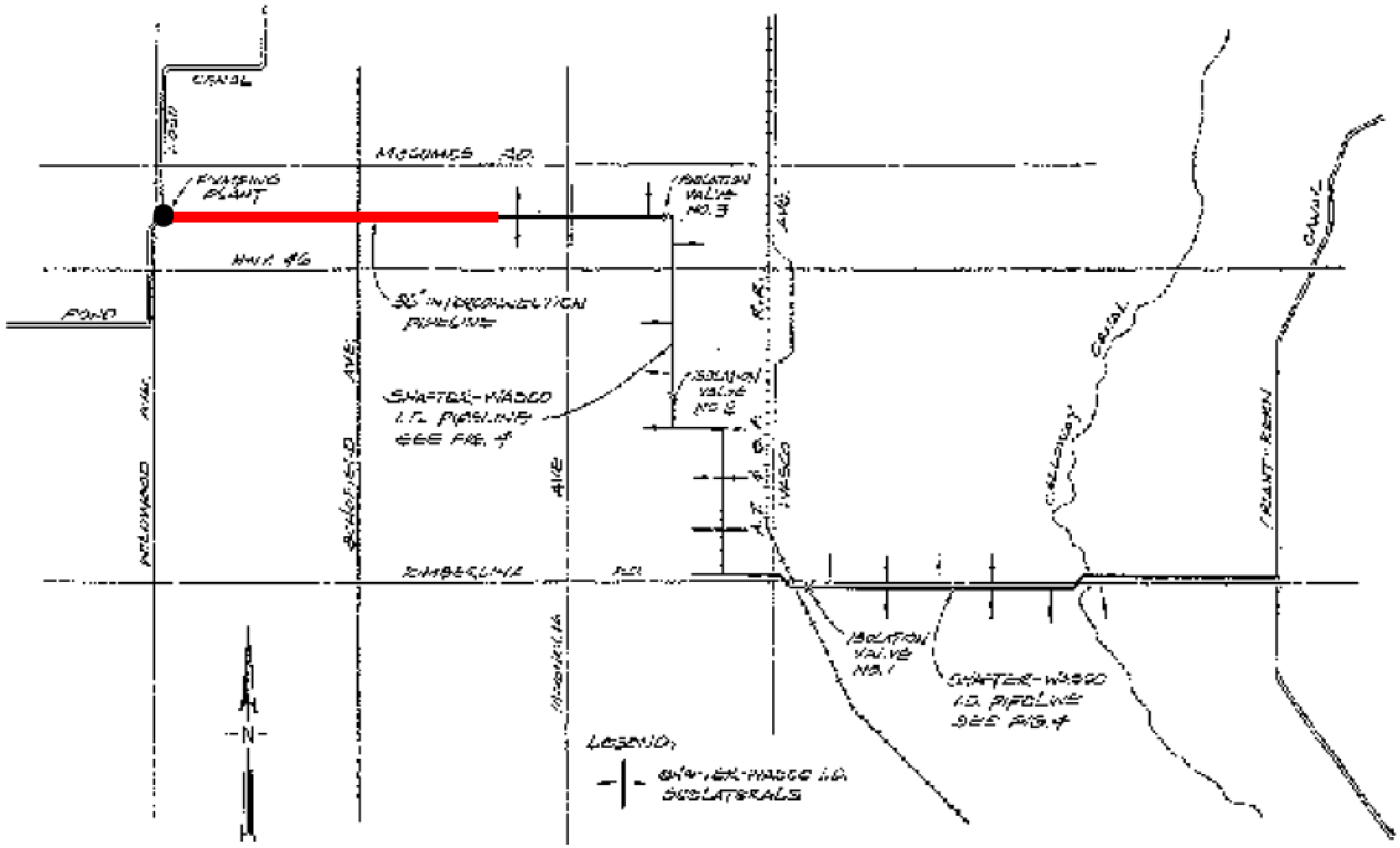


Figure 8. Existing Interconnection Between Semitropic Water Storage District and Shafter-Wasco Irrigation District

SWID/Semitropic Madera Avenue Interconnection

Another SWID/Semitropic project in consideration is the interconnection between the two districts on Madera Avenue (See Figures 7 & 9). This project is a 36-inch pipeline that would connect to the end of the 39-inch main transmission pipeline of Semitropic's Lateral B-230 to SWID's South System, a 33-inch pipeline located along Palm Avenue. This interconnection would operate in the same manner as the Kimberlina Road Interconnection. This project also has only been conceptually designed and is listed in the Poso Creek Integrated Regional Water Management Plan. Estimated at $5M with a capacity of design capacity of 50cfs, this is SWID's preferred project as there is already an existing connection to Semitropic on SWID's North System.

SWID/Semitropic Kimberlina Road Interconnection

Another interconnection project in consideration is the Kimberlina Road Interconnection between SWID and Semitropic (See Figures 7 & 9). This project would connect Semitropic's Lateral P-384 to SWID's North System main via a 60-inch intertie pipeline along Kimberlina Road. Unlike the existing intertie between Semitropic and SWID, which connects to the end of SWID's system, the intertie on Kimberlina Road would connect near the middle of SWID's North System, allowing for gravity flow to all the users downstream of the connection point.

In wet years, when there is excess non-project water available from the California Aqueduct through Semitropic's distribution system, this water can be used in-lieu of groundwater pumping by SWID growers. These facilities can also be used by Semitropic to receive water from east side sources, such as 215 Water from the Friant-Kern Canal or be used to convey Shafter-Wasco's high flow water into Semitropic's banking program. In dry years, these facilities will be used to return Shafter-Wasco's prior year banked water from Semitropic.

This project has only been conceptually designed and is one of the projects listed in the Poso Creek Integrated Regional Water Management Plan. It's estimated to cost $12M with a design capacity of 75 cfs.

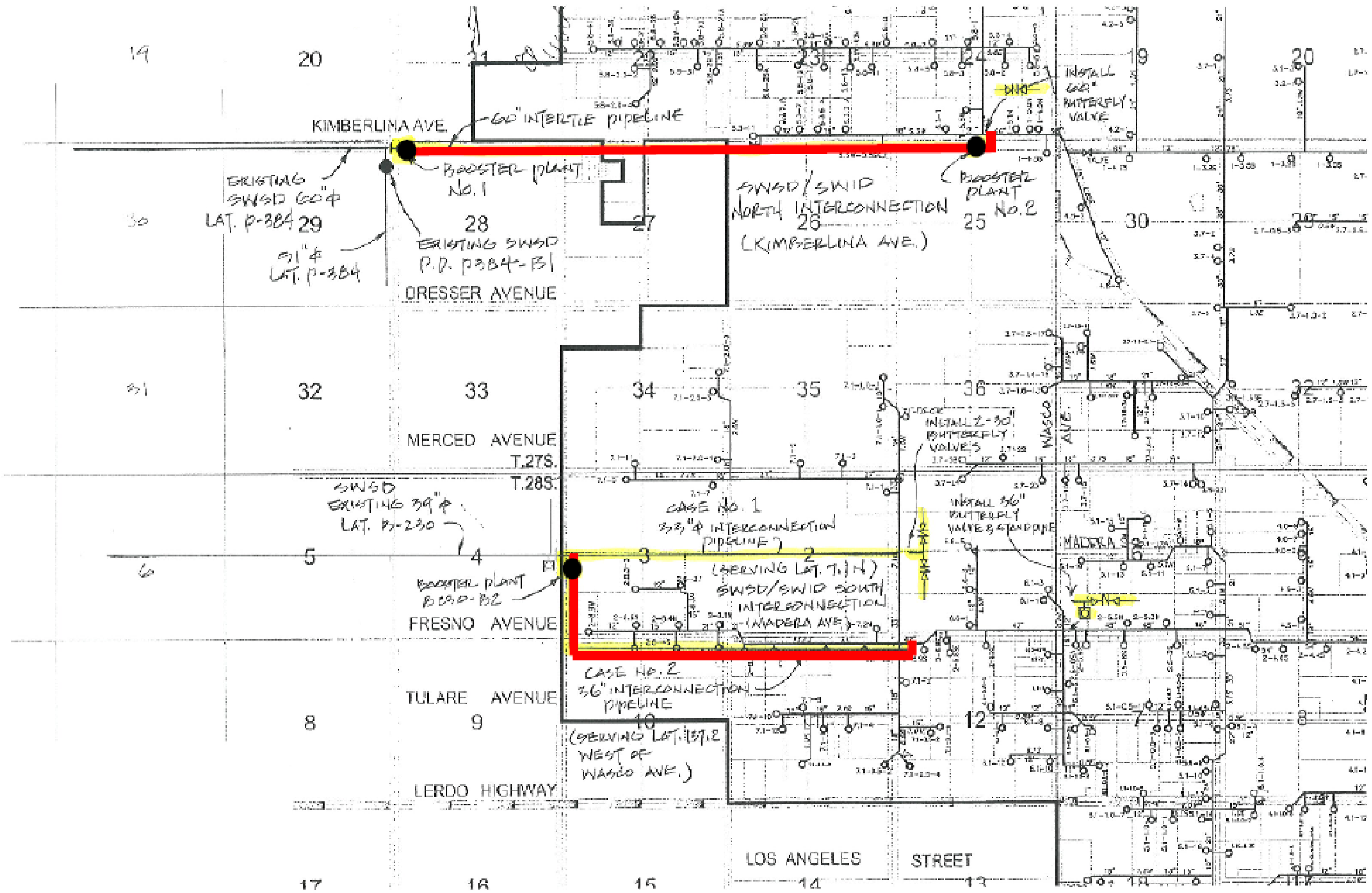


Figure 9. Proposed Kimberlina Road and Madera Avenue Interconnections between Semitropic Water Storage District and Shafter-Wasco Irrigation District

Multi-District Conveyance Facility

The Multi-District Conveyance Facility Project involves facilities that would essentially connect the California Aqueduct and the Friant-Kern Canal (See Figure 10). The goal is to provide a transmission facility to make greater use of surplus water existing in either the State Water Project or the Central Valley Project. Although several alignments and alternatives have been studied, they would all consist of a combination of canals, pipelines, and pumps that would start at Semitropic's 120-inch diameter Stored Water Recovery Unit pipeline and end near SWID's North System intake point at the Friant-Kern Canal.

Operating in the west-to-east mode, water would be conveyed directly to SWID's intake point (near the Friant-Kern Canal), allowing for the SWID system to operate as normal, by gravity, and eliminating the risk of damaging SWID's low-head pipes from pressurized reverse flow operation.

However, at an estimated cost of over $70M, the Multi-District Conveyance Facility would be very difficult to fund locally. There is also concern that the water supplies to be delivered from west to east to support the use of this facility are limited at this time due to the constraints in moving water south of the Sacramento-San Joaquin Delta.

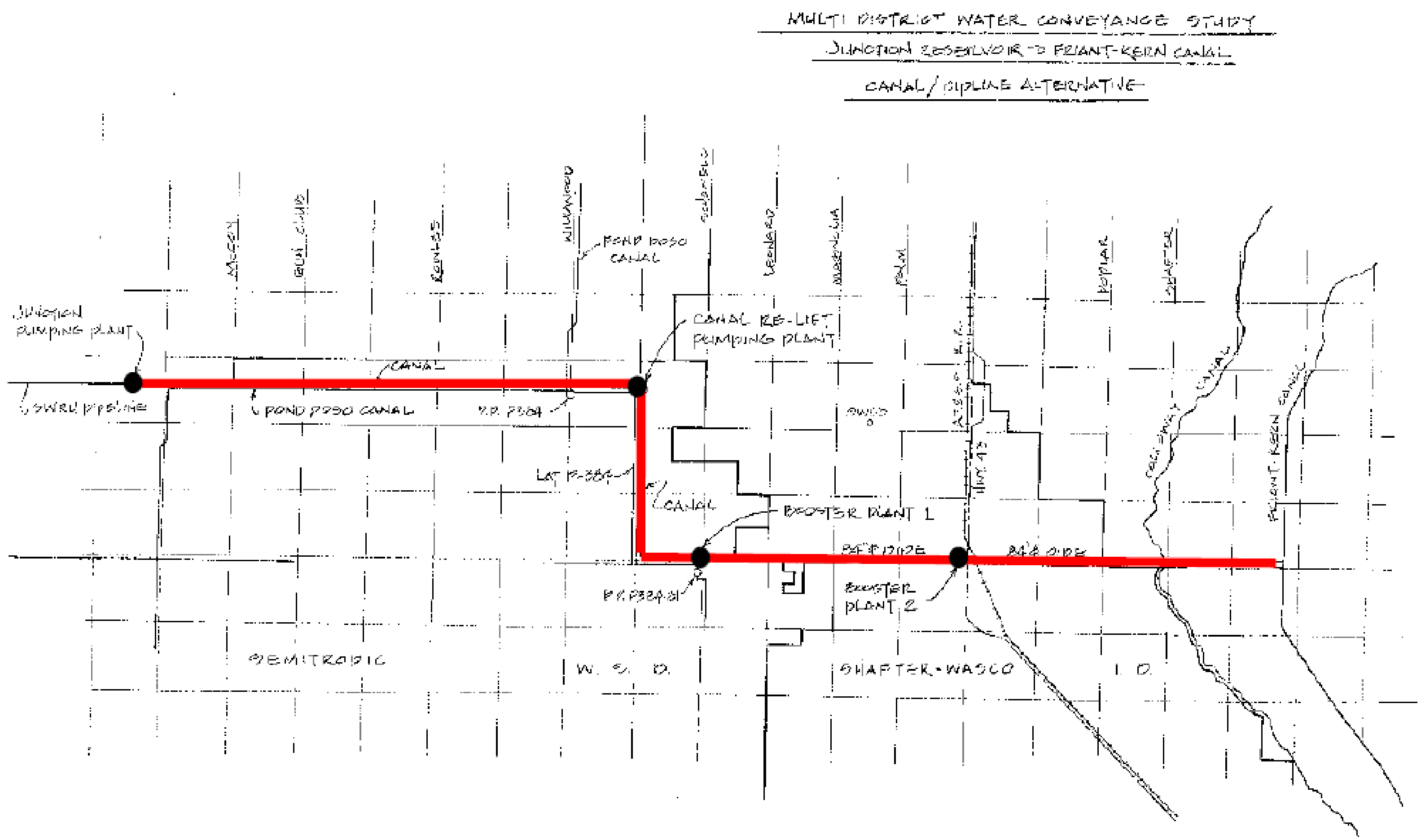


Figure 10. Proposed Multi-District Conveyance Facility from Semitropic's SWRU Pipeline to the Friant-Kern Canal

FINDINGS AND RECOMMENDATIONS

Table 2 shows the potential monthly capacity and variable operating costs of each project. Note that of the four interconnection projects with Semitropic, the Interconnection on Madera Avenue would be the least costly to operate per acre-feet of water.

Table 2. Project Capacities and Operating Costs

Project	Potential Monthly Capacity (ac-ft/mo)	Pumping Head (ft)	Capital Costs	Variable Operating Costs ($/ac-ft)
SWID/North Kern North Interconnection	4,500	-	$0.65M	-
SWID/North Kern South Interconnection	3,000	-	$0.60M	-
SWID/Semitropic Existing Interconnection	1,500	170	-	$29
SWID/Semitropic Madera Ave. Interconnection	3,000	60	$5M	$10
SWID/Semitropic Kimberlina Road Interconnection	4,500	70	$12M	$12
Multi-District Conveyance Facility	18,000	211	$70M	$36

To improve the operational capacity of the existing interconnection between SWID and Semitropic, GEI recommends that the districts meet to create operational protocols and mutually acceptable criteria for operation of the interconnection prior to any construction improvements to the interconnection are planned.

In order to implement the improvements to the existing interconnection with Semitropic and the three proposed conveyance connections (Kimberlina, Madera, Multi-District), SWID will need outside funding. A long-range goal will be to evaluate potential funding arrangements related to supporting the Semitropic Groundwater Bank, Reclamation Grant Programs, and possible funding through the Poso Creek IRWM Plan.

Regarding the three proposed new conveyance connections, SWID's preference would be to construct the Madera Avenue Interconnection between Semitropic and SWID's South System. There is no existing interconnection between SWID's South System with Semitropic, as an interconnection already exists on SWID's North System. The interconnection on Madera Avenue is also the least expensive of the proposed interconnections with Semitropic. However, SWID's first priority is to complete the North and South interconnections with North Kern. The North Interconnection is near completion, while the South Interconnection is ready for construction.

Therefore, SWID's overall preference and priority is to add conveyance flexibility by making the following improvements:

1. Finish the North Interconnection with North Kern
2. Construct the South Interconnection with North Kern
3. Improve the existing Interconnection with Semitropic
4. Construct the Madera Interconnection with Semitropic
5. Evaluate Kimberlina Interconnection as a regional project
6. Evaluate the Multi-District Conveyance Facility as a Regional Project

SUMMARY

As part of a larger system optimization review (SOR) that GEI Consultants, Bookman-Edmonston Division (GEI) conducted for the Poso Creek Integrated Regional Water Management Plan Region (Region), a portion of the budget was used to conduct a focused SOR to evaluate the Shafter-Wasco Irrigation District (SWID). In 2009, GEI met with SWID's General Manager and System Operator with the goal to document their ideas on ways to improve the SWID system, prior to the retirement of the System Operator. The SOR documented internal and internal and external opportunities for SWID to advance their current and future water management practices. SWID intends to continue replacing old farm turnouts and isolation valves as their operation and maintenance funds allow. SWID will consider funding from outside of their district to advance the identified conveyance improvements that would add water supply flexibility between SWID and neighboring districts.

THE USE OF ACOUSTIC DOPPLER SENSORS TO IMPROVE FLOW MEASUREMENTS DURING DROUGHT CONDITIONS IN SPAIN

M.J. Cook[1], PhD
Neus Tarafa[2]
Felix Bueno[3]
Andrés Alonso-Martirena[4]
Juan José Villegas[5]

ABSTRACT

In recent years, the northeast region of the Iberian Peninsula has experienced extreme drought, thus creating a need for water managers to have a better understanding of the available water resources. In the spring of 2007, the Agencia Catalana de l'Aigua (ACA) contracted Qualitas Instruments, SA to install five pulsed acoustic Doppler profilers at key sites near Girona, Spain with the goal of obtaining more accurate open channel flow measurements. In the past, these sites used water level as a surrogate to measure flow, however due to site conditions, rating curves at the site did not provide sufficient flow accuracy. In the scenarios presented in this paper, backwater effects from irrigation gates and water control structures in streams had an influence on flow monitoring at the sites. Rating curves typically break down in these situations because each water level does not have a unique associated flow value; that is to say for a given water level, there may be multiple flow values. Doppler sensors measure water depth and a velocity profile. Water depth data is used to determine flow area, which is multiplied by the average velocity that is measured by the Doppler sensor ultimately providing increased resolution and accuracy on flow measurements. Preliminary data indicate that for two sites (Canal Vinyals and Sentmenat), the rating curve method overestimated low flows conditions by an average of 68%, while the rating curve method at Resclosa Canet underestimated flows by 25%. Another irrigation canal, Canal Marge Esquerra, the Doppler sensor and Rating Curve provided similar data. Additionally, a stream monitoring site that applied a rating curve measured well during base flow, but was found to underestimate high flow conditions by approximately 31% when compared to the acoustic Doppler instrument, therefore additional investigations are needed for the site.

[1]Applications Engineer - SonTek/YSI Inc., 9940 Summers Ridge Road, San Diego, CA 92121 USA, mcook@sontek.com
[2]Director of Business Development - Qualitas Instruments, SA, Parc Tecnologic del Valles, Local 105, 08290, Cerdanyola, Spain, neus.tarafa@qualitasinstruments.com
[3]Environmental Engineer – Qualitas Instruments, SA, Parc Tecnologic del Valles, Local 105, 08290, Cerdanyola, Spain, felix.bueno@qualitasinstruments.com
[4]CEO - Qualitas Instruments, SA, Calle Toronga 31-1°, 28043 Madrid, Spain, andres.alonso-martirena@qualitasinstruments.com
[5]Head of Water Monitoring Networks - Agencia Catalana de l'Aigua, Calle Provenza 260 -3°, 08036 Barcelona, Spain, jvillegas@gencat.cat

INTRODUCTION

During 2004 to 2008 Catalunya (Figure 1), the autonomous region of Northeast Spain experienced the worse drought in nearly 100 years. In 2008 the drought conditions left many reservoirs at less than 20% capacity (Figure 2). Various options were studied to rectify the situation; among these were to transport water to the region by diverting and pumping water from another watershed as well as transporting water from southern France by train or boat. Additional drinking water resources will be provided from a desalination plant due to be completed in mid 2009. However considering the continuous stress on streams to provide source water to public works systems, irrigation water to growers, diversions for hydroelectric plants all while tying to maintain an ecosystem along the stream corridor this project was seen as a potential key for future water resources management.

In the spring of 2007, the Catalan Water Agency (ACA, L'Agencia Catalana de l'Aigua) contracted Qualitas Instruments SA (www.qualitasinstruments.com) to upgrade five key gauging stations, near Girona, Spain. These stations are located in area where the drought forced a delicate balance between irrigation, municipal and ecological use. Previously, the stations used water level as the primary surrogate measurement for flow, but have experienced problems with accuracy due to the back-water effect and irregular cross-section and distribution of flow. For the project, Qualitas Instruments SA installed 5 pulsed acoustic Doppler profilers (ADP) to monitor flow velocity and determine channel flow. ADPs measure a water velocity and calculate flow by multiplying the measured average velocity by the calculated flow area. Flow area is determined from a site specific stage-area relationship.

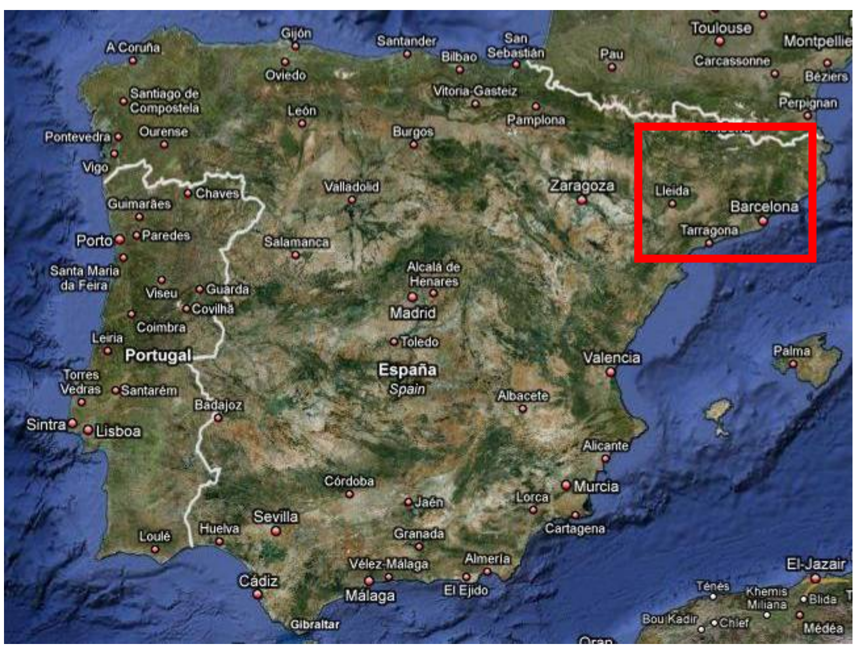


Figure 1. Map describing the general area of interest, Catalunya, Spain

Figure 2. Images from the extreme drought in Catalunya

MATERIALS AND METHODS

All sites in this study are equipped with a device to measure water level; that is used in conjunction with a rating curve (based on gagings in the field) to calculate flow. The rating curve converts water level data to flow data. Additionally, all sites for this study have included ADPs to determine flow. Both instruments, water level and ADP, were configured to collect data every 15 minutes with the ADP programmed to utilize a 1 minute averaging interval. Figure 3 below presents a detailed site map of the 5 stations involved in the study. All are located in the province of Girona, Spain. The following section provides detailed site descriptions of each site. In addition to Doppler sensors, each site was equipped with a QFL datalogger, designed and developed by Qualitas Instruments SA. The QFL not only logs and stores data files, but also allows for instrument signal processing, thus calibrating flow values reported by the ADP o gauging values conducted onsite by applying the modified power law.

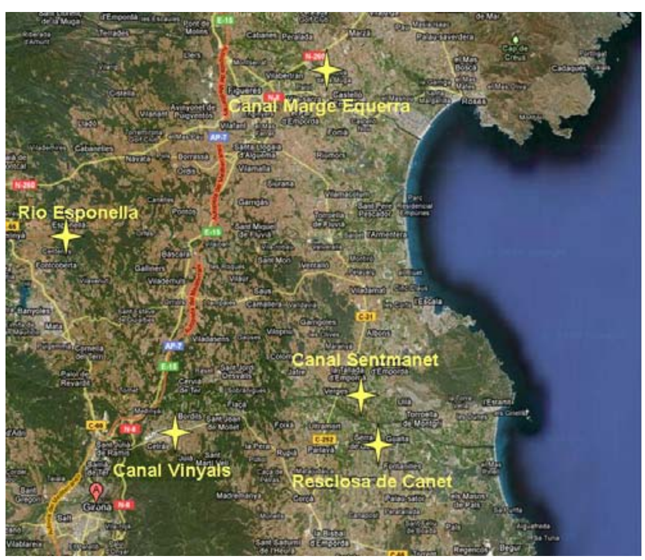


Figure 3. Detailed map of Doppler Instrument locations

Site Descriptions

Canal Vinyals This channel, as shown in Figure 4, is a rectangular cement irrigation canal with a regular distribution of water velocities and a low sedimentation rate. An Argonaut SW (3.0 MHz) was installed at the bottom of a straight section of the canal approximately 100 ft from the gage house. Typical flow depths range from 1 to 5 ft of water.

Figure 4. Photo of Canal Vinyals

Resclosa de Canet This irrigation canal (Figure 5, looking downstream) has an unpaved irregular bottom as well as an irregular distribution of water velocities across the channel. An Argonaut SL (1.5 MHz) was installed on the right bank of the canal at 1.70 ft from the bottom. The installation depth was determined to be optimal based on the review of historical data at the site. The SL was installed approximately 40 ft from the gage house.

Figure 5. Photo of Resclosa de Canet

Canal Sentmenat This irrigation canal (Figure 6) is a rectangular channel with an irregular bottom. Due to the curvature of the canal and the irregular bottom, irregular velocities are often observed. An Argonaut SL (1.5 MHz) was installed 2.62 ft above the deepest point of the canal and 2,600 ft from the gage house.

Figure 6. Photo of Canal Sentmenat

Canal Marge Esquerra de la Muga (Pont de Molins) This rectangular irrigation canal is concrete lined with a low sediment load. Since the canal has a regular distribution of velocities, the SW (3.0 MHz) was installed on the bottom of the canal just below the foot bridge and next to gage (Figure 7). The distance between the gaging station and the sensor is approximately 20 ft.

Figure 7. Photo of Canal Marge Esquerra de la Muga

Rio Fluvia - Esponella The Argonaut SL (1.5 MHz) was installed on the right bank of the Fluvia River near Eponella at 1.5 m from the deepest portion of the stream at a level that should always be submerged based on historical data. The stream has an uneven rocky channel bottom and irregular flow velocities. The SL is installed some 230 ft from the gage house. Figure 8 presents a photo of the downstream section of the Rio Fluvia, just upstream from where the SL is installed.

Figure 8. Photo of the Fluvia River near Esponella

RESULTS

Tables 1 -5 present results from verification gagings at each sites involved in the study. The results present good agreement between the gaging and the acoustic Doppler sensor flow data. One trend observed that the acoustic Doppler sensor generally provided a good measurement of flow at all sites however, low flows were nominally underestimated at the Resclosa de Canet and Vinyals and slightly overestimated flows at the Canal Marge Esquerra. It is important to note that the Vinyals and Canal Marge Esquerra sites are using the "Theroretical Method" for flow calculation, that is to say that the flow values are determined only by using the flow area (determined by the vertical beam/pressure sensor and the cross-sectional area of the station) and velocity profile determined by the acoustic Doppler sensor. All other sites are applying the adjusted power law via the QFL to calibrate raw data from the sensor to gaged data from the site. Additional accuracy can be obtained by using the velocity index method which allows the user to "calibrate" acoustic Doppler sensor to gaging data; in other words using regression analysis to compare the mean velocity from the gaging data to the mean velocity of the acoustic Doppler sensor.

Table 1. Flow data results for Canal Vinyals

Stage (ft)	Gaging (ft^3/s)	SW Discharge (ft^3/s)	% Difference
2.03	49.0	46.6	5.24
2.49	32.5	31.8	-1.96
3.58	47.3	45.9	2.99
3.61	43.4	45.2	-4.15

In addition to the data described in Table 1, data from a four day test deployment during steady flows in August 2008 indicated that the uncalibrated SW measured an average flow value of 42.3 ft^3/s compared to the rating curve value of 82.6 ft^3/s. Gaging at the site indicated that the flow value was 46.9 ft^3/s, thus a rating curve value overestimated flows by 95% .

Table 2. Flow data results for Resclosa de Canet

Stage (ft)	**Gaging (ft^3/s)**	**SL Discharge (ft^3/s)**	**% Difference**
4.10	24.3	24.7	0.01
5.84	79.4	70.9	11.99

Similar to the data in Table 2, flow data from an SL for three consecutive days of steady flow in August (2008) observed an average flow of 82.6 ft^3/s with a gaged value of 79.4 ft^3/s. This shows a good improvement from the rating curve value that corresponded to 61.8 ft^3/s; thus, the rating curve was 25% below actual flow values.

Table 3. Flow data results for Sentmenat

Stage (ft)	**Gaging (ft^3/s)**	**SL Discharge (ft^3/s)**	**% Difference**
0.79	16.6	16.2	1.71

In addition to the data in Table 3, data from a three day monitoring period in June 2008 with steady flow determined that flow from the SL was 17.6 ft^3/s which compared to the rating curve value of 24.7 ft^3/s; gaging value from the site was 16.9 ft^3/s. This identifies that the rating curve was overestimating flows by 40%.

Table 4. Flow data results for Canal Marge Esquerra

Stage (ft)	**Gaging (ft^3/s)**	**SW Discharge (ft^3/s)**	**% Difference**
3.28	12.0	10.6	10.45
3.31	13.4	14.1	-5.82
4.59	70.9	70.6	-0.40

In general, SW and rating curve data have compared well to each other during all measurement periods.

Table 5. Flow data results for Rio Fluvia - Esponella

Stage (ft)	**Gaging (ft^3/s)**	**SL Discharge (ft^3/s)**	**% Difference**
1.18	84.7	84.7	0.00
1.77	198.0	197.6	0.18
2.36	370.5	367.0	0.96

Flow data from the SL and the rating curve are comparable overtime during steady flows for four days in June; however the SL measured much higher flow values than the rating curve during high flow periods (917 ft^3/s for the ADP compared to 635 ft^3/s for the rating curve). Additional gagings need to be completed at higher flows to determine which flow value is more accurate. In the case that the SL needs additional accuracy a velocity index can be completed to fine-tune/calibrate the acoustic Doppler instrument. Table 6 provides a summary comparing the ADP and rating curve data.

Table 6. Summary of data comparing ADP to Rating Curve data

Station	Flow ADP (ft^3/s)	Flow Rating Curve (ft^3/s)	Gaging (ft^3/s)	% Difference (Rating Curve – ADP)
Canal Vinyals	42.3	82.6	46.9	95%
Resclosa Canet	82.6	61.8	79.4	-25%
Canal Sentmenat	17.6	24.7	16.9	40%
Canal Marge Esquerra	10.5	11.3	12.0	8%
Rio Fluvia	917	635	---	-31%

SUMMARY AND CONCLUSIONS

Considering the intense drought in Northeast Spain during 2004-2008, water managers were forced to look for solutions to better quantify flow values in order to maintain delicate balance between municipal, agricultural and ecological use. Five gaging stations had ADPs installed as flow measuring instruments in order to provide more accurate flow measurements. Based on the information provided above, ADPs provided increased accuracy for flow measurements by applying the theoretical flow calculation or by applying the adjusted power law to velocity. Additional fine-tuning or accuracy can be achieved over time by calibrating or conducting a velocity index for the sites, however some sites performed well using raw data from the ADP. The gaging sites included four irrigation canals and one river. Preliminary data indicate that for two irrigation canals the rating curve method overestimated low flows conditions by an average of 67.5%, while one canal underestimated flow by 25%. An additional irrigation canal using a rating curve compared fairly well to ADP data. Lastly, a stream monitoring site had comparable data during base flow, but was found to underestimate high flow conditions by approximately 30% when comparing data from the ADP and rating curve, however no gaging data was available as a check; this suggests that additional investigations need to be completed.

FUTURE FUNDING OPPORTUNITIES FOR IRRIGATION DISTRICTS — WHAT IS ON THE HORIZON?

L. Ospina[1]
E. Ringer, PE[2]

ABSTRACT

Water shortfalls have placed irrigation districts center stage in water publicity. The lack of public knowledge on how irrigation districts divert and convey water has precipitated questions regarding the operations and water management practices of these districts. As irrigation users implement new technologies or restore existing systems, a considerable quantity of applied water is expected to be managed more effectively. Public perception is that water conservation is expected to enhance irrigation and provide favorable results, such as, less water use, increased yield, and decreased operation costs.

The purpose of this paper is <u>not</u> to debate the effectiveness of water conservation programs intended for irrigated agriculture, but to identify funding opportunities, (grants and/or loans), that are available to irrigation districts to help achieve the goal of water conservation. Many funding opportunities focus on assisting irrigation districts in identifying best management practices for water conservation. Examples of applied technology for the purpose of achieving water conservation in irrigated agriculture have been presented by numerous USCID authors and vigorously debated for years.

This paper presents the results of GEI/Bookman-Edmonston Consultants (GEI) evaluation of funding opportunities specific to agricultural agencies including state, federal, and local grant and loan opportunities. Funding is available in various categories including water conservation, water recycling, groundwater management, and activities aimed at enhancing local water supply reliability. Key federal, state and local agencies have a long-term goal of providing assistance that will enable the implementation of better management practices and finance feasible, cost effective agricultural water conservation projects or programs.

INTRODUCTION

The purpose of this paper is <u>not</u> to debate the effectiveness of water conservation programs intended for irrigated agriculture, but to identify avenues to the funding opportunities, such as grants and/or loans, that are available to irrigation districts to help achieve the goal of water conservation. Many funding opportunities focus on assisting irrigation districts in identifying and implementing best management practices for water conservation. Examples of applied technology for the purpose of achieving water conservation in irrigated agriculture have been presented by numerous USCID authors

[1] Senior Water Quality Consultant, GEI Consultants Inc., Bookman-Edmonston Division, 101 N. Brand., Suite 1780 Glendale, CA 91203 lospina@geiconsultants.com , 818-552-6412 for funding opportunity assistance.
[2] Associate Staff Engineer, GEI Consultants Inc., Bookman-Edmonston Division, 101 N. Brand Blvd., Suite 1780 Glendale, CA 91203 eringer@geiconsultants.com

and vigorously debated for years. The goal of this paper is to help guide irrigation districts through the labyrinth of funding opportunities on the horizon.

BACKGROUND

A brief description is provided as background information for each of the Propositions referenced in this report.

Proposition 13 (2000) - Groundwater Storage and Groundwater Recharge (DWR, 2000)

The Safe Drinking Water, Clean Water, Watershed Protection and Flood Protection Act, also known as Proposition 13, was enacted on March 7, 2000 and authorized 1.97 billion dollars in bonds. A total of $200 million in funds was allocated for the Groundwater Storage Program. Under the Groundwater Storage Program, the Department of Water Resources (DWR) administers grants for feasibility studies and construction projects to facilitate conjunctive management of surface water and groundwater to improve water supply reliability (DWR, 2002a).

Proposition 50/84 (2002) - Water Security, Clean Drinking Water, Coastal and Beach Protection Act (DWR, 2006)

The Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006, enacted on November 7, 2006, authorized $5.4 billion in bond to fund safe drinking water, water quality and supply, flood control, waterway and natural resource protection, water pollution and contamination control, state and local park improvements, public access to natural resources, and water conservation efforts (Bond Accountability, 2010a).

Proposition 1E (2006) – Disaster Preparedness and Flood Protection Bond Act (DWR, 2000)

The Disaster Preparedness and Flood Protection Bond Act was passed in 2006 and authorized $4.09 billion in bond funds for rebuilding and repairing flood control structures. The funds would be used to protect homes and lives and California's drinking water supply system. This act is enhanced by $800 million from Proposition 84 for flood control projects (Bond Accountability 2010b).

ARRA (2010) – American Recovery and Reinvestment Act

Recovery Act was signed into law by President Obama on February 17th, 2009. The Act is a response to a crisis unlike any since the Great Depression, and includes measures to modernize our nation's infrastructure, enhance energy independence, expand educational opportunities, preserve and improve affordable health care, provide tax relief, and protect those in greatest need

Also included as Appendix A is a grant funding matrix for further use in the evaluation of these funding sources. This matrix can be used to facilitate comparisons and help identify key issues, comments, application deadlines, etc.

Funding Opportunities

IRWMPs The Integrated Regional Water Management Grant Program's intent is to promote and practice integrated regional water management to ensure sustainable water uses, reliable water supplies, better water quality, environmental stewardship, efficient urban development, protection of agriculture, and a strong economy.

Funding for the IRWMP's is derived from two propositions:

1. Proposition 50, the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002, passed by California voters in November 2002. Implementation of the Proposition 50 Chapter 8, bond funding is jointly administered by DWR and the SWRCB.

2. Proposition 84, the Safe Drinking Water, Water Quality and Supply, Flood Control, River and Costal Protection Act, passed by California voters in November 2006. Administered by DWR, Proposition 84 includes funding for the IRWM Grant Programs and related projects.

The Integrated Regional Water Management planning process is a local and regional water management approach preferred by DWR and SWRCB. It is aimed at securing long-term water supply reliability within California by first recognizing the inter-connectivity of water supplies and the environment and then pursuing projects yielding multiple benefits for water supplies, water quality, and natural resources. A completed IRWMP will provide a mechanism for coordinating, refining, and integrating existing planning efforts within a comprehensive, regional context; identifying specific regional and watershed-based priorities for implementation projects; and providing funding support for the plans, programs, projects, and priorities of existing agencies and stakeholders. Preference to a regional approach is strongly prioritized for the receipt of grant funding identified below.

Proposition 84 Funding is still available through DWR through Proposition 84, the Safe Drinking Water, Water Quality and Supply, Flood Control, River and Costal Protection Act, passed by California voters in November 2006. Administered by DWR, Proposition 84 includes funding for the IRWMP grant program and provides approximately $1.4 billion in additional funding for IRWMP and projects. The bond would provide funds for water supply projects in 12 regions throughout California and also for local and regional conveyance projects that support regional and interregional connectivity and water management. The funds are assigned to each of the 12 regions as follows in Table 1.

Table 1. Funding Regions

Region	Funding Amount
North Coast	$45,000,000
San Francisco Bay	$132,000,000
Central Coast	$58,000,000
Los Angeles subregion	$198,000,000
Santa Ana subregion	$128,000,000
San Diego subregion	$87,000,000
Sacramento River	$76,000,000
San Joaquin River	$64,000,000
Tulare/Kern	$70,000,000
North/South Lahonton	$51,000,000
Colorado River Basin	$47,000,000
Mountain Counties Overlay	$44,000,000

As part of Proposition 84, a Region Acceptance Process (RAP) has been developed and is used to evaluate and accept an IRWMP Region. DWR is the overseer of applications submitted in the RAP process. Currently, the recognized Regions are published on DWR's website. DWR is developing the solicitations for future funding expected to be derived from Proposition 84.

Grants: State, Federal, NGOs

Planning Grants The Planning Grants are intended to foster development or completion of IRWMPs or components thereof, to enhance regional planning efforts, and to assist more applicants to become eligible for Implementation Grant funding. The first RAP was completed in 2009. Final decisions on regional acceptance were made in late 2009. Potential uses for these funds include development of a Regional IRWMP. Irrigation districts that are stakeholders of an IRWMP would qualify to receive funds. As well as potential application towards the development of Environmental Impact Reports associated with projects that result from the IRP/IRWMP process.

Implementation Grants Proposition 50, Chapter 8, provided approximately $380 million for two types of competitive grants for the IRWM Grant Program, planning and implementation. Implementation grants funded projects that met one or more of the program objectives of protecting communities from drought, protecting and improving water quality, and improving local water security by reducing dependence on imported water. All grant funds from Proposition 50 have been allocated; however, it is anticipated that DWR will allocate funds from Proposition 84 to help fund future implementation

Loans: State, Federal Current legislation has approved a proposed 2010 Budget of $3.9 billion for the EPA Water Revolving Loan Program. The language in the budget outline states that the Administration will support "program reforms" that will put the clean water and drinking water State Revolving Fund (SRF) on a "firmer foundation" and will work with State and local partners to develop a sustainability policy including management and pricing for future infrastructure funded through SRFs to encourage conservation and to provide adequate long-term funding for future capital needs. Portions of these funds may be applied to regional IRWMP programs that focus on water conservation programs that would benefit an irrigation district service area.

Federal Water Bank Fund

In addition to the increases for the EPA water revolving funds, the budget outline proposes $5 billion per year for a new Infrastructure Bank designed to deliver funding to priority projects with significant national or regional economic benefit. The Federal Water Infrastructure Bank would be authorized to borrow money from the federal Treasury at very low rates. In turn, the bank would make low-interest loans for larger projects that typically are too big to access the SRF. Proposals for an infrastructure bank and a water trust fund are under congressional discussion and under the formative stage. If an irrigation district were to embark in a regional IRWMP funds from the bank could be obtained for projects providing a regional benefit.

Water Trust Fund

Representatives have recently introduced the Water Protection and Reinvestment Act of 2009 (HR 3202). This legislation would create a water trust fund that would generate $12 billion annually from fiscal year 2010 through fiscal year 2014, for total funding of nearly $60 billion to local communities to address drinking water and wastewater infrastructure needs. The fund would be paid for with several small taxes on industries that produce and consume water-based goods, as well as items that are flushed into sewer systems.

Proposals for an infrastructure bank and a water trust fund are under congressional discussion and in the formative stage. Irrigation districts could benefit from the development of regional projects that would serve to address regional drinking water and infrastructure needs. It is anticipated that each $1 billion spent on water infrastructure could create approximately 35,000 jobs. This is particularly important for irrigation districts whose plan identifies economic growth and stimulus as a priority in the Region.

Reliable Water Supply Bond Act of 2008

This bond (Senate Bill 59), if approved by voters, would authorize the issuance of bonds in the amount of $3.95 billion. Of this amount, $500 million would be available for the planning, design, and construction of locally managed conjunctive use and groundwater storage projects, which are consistent with an adopted IRWMP. Additionally, a total of $200 million would be available for agricultural and urban water use efficiency projects, which are consistent with an adopted IRWMP. If approved by voters, it is anticipated that this funding source would become available in late 2008/early 2009. Schedules are still pending.

Recycled Water/ Desalination Funding Programs

Financial assistance programs play a critical role in the development of local resources including recycled and brackish groundwater supplies. There are a number of state and federal financial assistance programs available to irrigation districts which are further described in this chapter and include: the SWRCB's grant and low-interest loan programs; the U.S. Bureau of Reclamation's Title XVI Grant Program; federal Propositions, and other local partnership and funding opportunities. Together, these programs could provide funding assistance for any proposed irrigation district desalination or recycled water projects, from initial planning and design to construction and operation. Several of the funding opportunities mentioned in the section below have elements of the program that apply to both recycled water and desalination projects.

Reclamation Wastewater and Groundwater Study and Facilities Act - Title XVI

The USBR Title XVI Program is a significant source of funding for area water recycling projects. Title XVI of Public Law 102-575, the Reclamation Wastewater and Groundwater Study and Facilities Act, authorizes the federal government to fund up to 25 percent of the capital cost of recycling projects, which can include an interconnected system of recycling projects serving an irrigation district service area.

Also known as Title XVI, the act directs the Secretary of the Interior to undertake a program to investigate and identify opportunities for water reclamation and reuse of municipal, industrial, domestic, and agricultural wastewater, and naturally impaired ground and surface waters, and for design and construction of demonstration and permanent facilities to reclaim and reuse wastewater. It also authorized the Secretary to conduct research, including desalting, for the reclamation of wastewater and naturally impaired ground and surface waters.

State Revolving Fund (SRF) / Water Recycling Loan Program (WRLP) / Water Recycling Grants (WRG)

The SRF, WRLP, and WRG provide agencies with low-interest construction loans for water recycling and groundwater development projects. These loans carry an interest rate equal to half of the State's general obligation bond interest rate. This below market interest rate can result in substantial savings on debt service. WRGs, subject to availability, provide up to 25 percent of eligible construction costs with a maximum $5 million cap per agency. Planning grants of up to $75,000 maximum are also provided for eligible facilities planning/feasibility study costs. Each Program is further described in detail below.

Clean Water State Revolving Fund The Federal Water Pollution Control Act (Clean Water Act or CWA), as amended in 1987, provides for establishment of a Clean Water State Revolving Fund (CWSRF) program. The program is funded by federal grants, state funds, and revenue bonds. The purpose of the CWSRF program is to implement the CWA and various State laws by providing financial assistance for the construction of facilities or implementation of measures necessary to address water quality problems and to prevent pollution of the waters of the State.

The CWSRF Loan Program provides low-interest loan funding for construction of publicly-owned wastewater treatment facilities, water recycling facilities, as well as, expanded use projects such as implementation of non-point source (NPS) projects or programs, development and implementation of Estuary Comprehensive Conservation and Management Plans, and storm water treatment.

Eligible applicants are local public agencies, non-profit organizations, and private parties. Eligible project types include publicly-owned wastewater treatment facilities, local sewers, sewer interceptors, and water reclamation facilities, as well as, nonpoint source pollution control projects. There is approximately $200 to $300 million available annually within California, with a continuous application process. The SWRCB is currently accepting applications.

Water Recycling Funding Program (WRFP) The SWRCB provides funding for the planning, design, and construction of water recycling projects. Water recycling planning grant funding is available to assist public agencies with their feasibility study and planning efforts. Construction projects may be funded with a combination of grants and loans. Privately owned water utilities that are regulated by the Public Utilities Commission are also eligible to apply for construction grants.

Program Funding Sources that support the Water Recycling Program are listed below:

1. The Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002.

2. Proposition 50 (2002): Chapter 7, Section 79550(g) authorizes grants for water recycling projects that meet the goals and objectives of the California Bay-Delta Program (CALFED) and are consistent with the CALFED Record of Decision.

3. SRF Loan Program: The SRF loan program provides low-interest loans to public agencies for planning, design, and construction of projects that recycle water to replace the use of the State and/or local water supply.

4. The Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection

5. Proposition 13 (2000): The funds for construction grants and loans from Proposition 13 have essentially been exhausted. However, a small amount of money comes into the program each year from loan repayments. This provides the source of funds for the planning grant program. As the size of the planning grants is small ($75,000 maximum), the repayment funds are sufficient to maintain this program.

Water Recycling Facilities Planning Grant Program (FPGP) The Water Recycling FPGP, a subprogram under the WRFP, provides grants to public agencies for facilities planning studies. The purpose of the FPGP is to assist agencies in the preparation of facilities planning studies for water recycling using treated municipal wastewater and/or treated groundwater from sources contaminated. In addition to encouraging new recycling planning studies, these funds are intended to supplement local funds and enhance the quality of local planning efforts.

FPGP Grants are provided for facilities planning studies to determine the feasibility of using recycled water to offset the use of fresh/potable water from state and/or local supplies. Pollution control studies, in which water recycling is an alternative, are not eligible. The grant will cover 50 percent of eligible costs up to $75,000.

Construction Funding Program Funding for the construction of water recycling facilities is primarily provided from Proposition 50 and the SRF loan program. Table 2 below summarizes the various project categories under the Construction Funding Program.

Table 2. Description of Project Categories

Category Type	**Description**
Category I – State Water Supply and the Delta	• Provide for treatment and delivery of municipal wastewater or groundwater contamination, for uses (including groundwater recharge) that will offset State Water supplies; and • Provide benefits to the Delta by: • Increasing the average water flow into the Delta, or • Reducing water pumping from the Delta.
Category II – State Water Supply	Provide for treatment and delivery of municipal wastewater or groundwater contamination remediation, for uses (including groundwater recharge that replace the use of the State water supply with recycled water, but do not provide benefits to the Delta.
Category III – Local Water Supply	Provide for treatment and delivery of municipal wastewater to users that replace the use of local water supply with recycled water.
Category IV – Local Groundwater Reclamation	Provide treatment and reuse of groundwater contaminated due to human activity; and provide local water supply benefits

Projects within the following two categories, Category V and VI, may only be considered for funding by the SRF Loan Program for the objective of pollution control, if applicable.	
Category V – Pollution Control	Provide for treatment and disposal of municipal wastewater to meet waste discharge requirements imposed for water pollution control.
Category VI – Miscellaneous	Are projects that do not have identifiable benefits to the State or local water supply.

Agricultural Drainage Program

The Agricultural Drainage Loan Program was created by the Water Conservation and Water Quality Bond Act of 1986 to address treatment, storage, conveyance, or disposal of agricultural drainage water that threatens waters of the State. There is a funding cap of $20 million for implementation projects and $100,000 for feasibility studies. Loan repayments are for a period of up to 20 years.

Eligible applicants include any city, county, district, joint powers authority, or other political subdivision of the State involved with water management. Projects must address treatment, storage, conveyance, or disposal of agricultural drainage that threaten waters of the State. The SWRCB is currently accepting applications and has a total funding pool of $11.3 million.

Agricultural Drainage Management Loan Program

The Agricultural Drainage Management Loan Program, created by Proposition 204 and distributed through the Agricultural Drainage Management Subaccount, provides loan and grant funding for Drainage Water Management Units. Drainage Water Management Units are land and facilities for the treatment, storage, conveyance, reduction, or disposal of agricultural drainage water that, if discharged untreated, would pollute or threaten to pollute the waters of the State. This program is available to any city, county, district, joint power authority, or other political subdivision of the State involved with water management. Projects must address treatment, storage, conveyance or disposal of agricultural drainage that threaten waters of the State. The SWRCB is currently accepting applications and has a total funding pool of $6.67 million.

Local Groundwater Assistance Program

LGA grants provide local public agencies with up to $250,000 to conduct groundwater studies or carry out groundwater monitoring and management activities. Approximately $4.7 million in funding from Proposition 84 is available for the fiscal year 2009-2010 LGA Grant Program.

Priority for Proposition 84 LGA grant funding will be given to local public agencies that have adopted a Groundwater Management Plan and demonstrate collaboration with other agencies in the management of a groundwater basin.

Small Community Wastewater Grant

The Small Community Wastewater Grant (SCWG) Program, most recently funded by Propositions 40 and 50, provides grant assistance for the planning, design, and construction of publicly-owned wastewater treatment and collection facilities. Grants are available for small communities (i.e., with a population of 20,000 persons or less) with financial hardship (i.e., annual median household income [MHI] is 80 percent of the Statewide MHI, or less).

American Recovery and Reinvestment Act (ARRA)

In the face of an economic crisis, the Federal government has provided resources through the American Recovery and Reinvestment Act providing stimulus funding for economic growth and infrastructure improvements represents a strategic and significant opportunity for irrigation districts. HR 1, the American Recovery and Reinvestment Act provides for significant emergency funding for public works infrastructure as part of a $787 billion package of spending and tax cuts. The package includes over $7 billion for drinking water and wastewater projects. The EPA clean water and drinking water SRF programs will receive $6 billion, including $4 billion for the clean water SRF and $2 billion for the drinking water SRF.

Through the American Recovery and Reinvestment Act, California will receive $2.5 billion (Figure 1) to complete some of the water and environmental projects whose funding sources have been suspended.

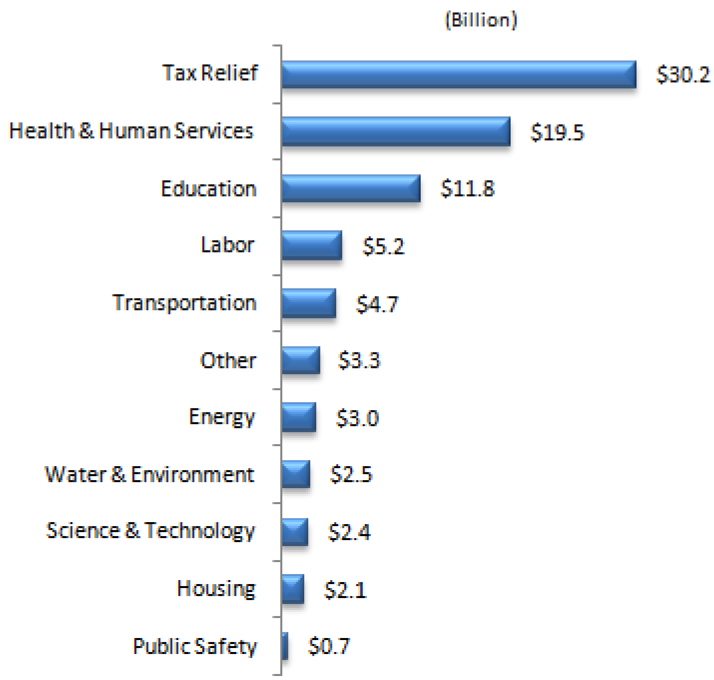


Figure 1. ARRA $ 85 Billion for California[3]

Water Conservation Initiative (Formerly called Water for America Initiative)

USBR is responsible for administering and managing the Water Conservation Initiative Program. However, there are opportunities that the United States Geological Survey (USGS) brought in as a managing partner depending on whether or not the focus of the project is agriculturally related. For all of the subprograms that fall under the Water Conservation Initiative Parent program, each year a new solicitation is put together and released. The next opportunity for programs mentioned below is expected in early 2010.

Advanced Water Treatment Grants The Advanced Water Treatment Grants will provide funding for pilot or demonstration projects that will test the viability of advanced water treatment technologies. These grants will help create new water supplies to address water supply imbalances. Advanced water treatment technologies generally include methods that remove salt, other difficult to remove dissolved and suspended matter, including viruses and bacteria that are not removed by conventional treatment (i.e., simple screening, coagulation/ flocculation, chlorination, chloramination, or ozonation).

Preferred projects include projects that demonstrate reverse osmosis membranes, pre-treatment processes, concentrate disposal, or other advanced water treatment processes. The purpose of these projects is to demonstrate the technical and economic viability of using an impaired water source within a specific locale. These grants will not be available for the construction of a full scale plant.

---

[3] American Recovery and Reinvestment Act 2009 , California

Water Marketing and Efficiency Grants Through the Challenge Grant Program - Water Marketing and Efficiency Grants, Reclamation provides 50/50 cost share funding to irrigation and water districts and states for projects focused on water conservation, efficiency, and water marketing. Projects are selected through a competitive process, based on their ability to meet the goals identified in Water for America Implementation Plan. The focus is on projects that can be completed within 24 months that will help sustainable water supplies in the western United States. The Water for America Initiative is a multi-agency, U.S. Department of the Interior initiative that will help communities meet increasing demands on limited water supplies through collaborative projects, water conservation technologies, and expanded information sharing.

The Water for America Implementation Plan sets for three overall initiatives/strategies. For 2010, the program is in the process of changing the name from Water for America to Water Conservation.

Reclamation will focus its efforts on two of the three strategies: (1) Plan for Our Nation's Water Future, (2) Expand, Protect, and Conserve Our Nation's Water Resources, and (3) Enhance our Nation's Water Knowledge; will be undertaken by the USGS.

The strategy to Plan for Our Nation's Water Future includes Reclamation's long-standing Investigations Program and a new Basin Studies Program that will focus on comprehensive water supply and demand studies to assess the impact of increased water demands.

The second strategy, Expand, Protect, and Conserve our Nation's Water Resources, will include two existing programs, the Challenge Grant Program (formerly part of Water 2025 and Water for America) and the Water Conservation Field Services Program. Through another component of this strategy, Reclamation will accelerate Endangered Species Act compliance activities to maintain and improve existing populations of listed or proposed species and critical habitat affected by Reclamation's projects and programs.

System Optimization Review Grants System Optimization Reviews were a new initiative under the Water for America Challenge Grant program. A System Optimization Review is a broad look at system-wide efficiency focused on improving efficiency and operations of a water delivery system, water district, or water basin. The Review results in a plan of action that focuses on improving efficiency and operations on a regional and basin perspective. Those recommended improvements may then be eligible for the Water Marketing and Efficiency Grant funding. Applicants must include an irrigation and/or water district, tribal water authority, state governmental entity with water management authority, or entities created under state water law with water delivery authority within the 17 western states.

SUMMARY AND RECOMMENDATIONS

GEI has provided a brief summary of each funding opportunity that is applicable and available to the agricultural and irrigation district community. GEI has summarized the funding amounts, eligibility requirements, and timing and schedule for the districts to review and decide which funding source might be identified as the best match for funding.

GEI has included a grant funding matrix for district use in the further evaluation of these funding sources (Appendix A). This matrix can be used to facilitate comparisons and helps to identify key issues, comments, application deadlines, etc. Additionally, GEI has provided the links to the funding sources and each proposition below for further review of the funding opportunities identified in this report

REFERENCES

State of California Department of Water Resources, Division of Planning and Local Assistance. *Proposition 13 Groundwater Grants and Loans Program Summary*. [Online] 2002.

State of California Natural Resources Agency. *Summary of Programs in Proposition 50.* [Online] 2005.

State of California Strategic Growth Plan, Bond Accountability. *Proposition 84 Bond Information* [Online] 2010a.

State of California Strategic Growth Plan, Bond Accountability. *Proposition 1E Bond Information [Online]*. 2010b.

State of Califronia Department of Water Resources, *2009 Comprehensive Water Package Special Session Policy Bills and Bond Summary*, 2009.

APPENDIX A

GRANT FUNDING MATRIX

Program	Brief Description	Key Points	Key Application Dates	Contact Info
Federal Stimulus (American Recovery & Reinstatement Act) in California				
CDPH, Safe Drinking Water State Revolving Funds	Projects that assist in achieving or maintaining compliance with the Safe Drinking Water Act (SDWA). Includes source water protection projects	$160M available plus regular annual allocation of - $80M Planning, design & construction projects; $20M max/yr/project, 20 yr payback; $30M max/yr/entity, 20 yr payback Planning only: $100k max/project, 5 yr payback; Current interest rate: 2.3%; principal forgiveness or negative interest loans may be available	The Universal Pre-application is now open until Feb 27, 2009. It is anticipated invitations to submit a full application will go out in April 2009, then applicant has 60 days to complete application (June 2009) and 60 days later must begin construction (Aug 2009).	http://www.cdph.ca.gov/services/funding/Pages/SRF.aspx 916-449-5600 mailto:sdwsrf@cdph.ca.gov
SWRCB, Clean Water State Revolving Fund	Eligible applicants; POTW (local public agencies) & NPS (local public agencies, non-profit organizations, and private parties) Eligible Projects: - Publicly owned treatment facilities such as: wastewater treatment, including installation and major rehabilitation of sewer lines, and storm water prevention/reduction - Water recycling projects - Nonpoint source and estuary enhancements projects (expanded use)	No state matching required. Program funding: $284.6M No upper limit for project; however maximum annual funding cap of $50M per agency per year.	Applications under Economic Stimulus Package due March 24 through FAAST. Applications are accepted on a revolving basis.	www.swrcb.ca.gov/water_issues/programs/grants_loans/srf/ mailto:CleanWaterSRF@waterboards.ca.gov Christine White 916-341-5795 cwhite@waterboards.ca.gov
USBR CALFED Bay Delta		$50M as stated in ARRA		

Program	Brief Description	Key Points	Key Application Dates	Contact Info
USBR Title XVI	Recycled water feasibility investigations, preliminary engineering studies and research projects. Brackish water desalination is also considered.	$126M as stated in ARRA		
State				
Drinking Water, General – CA Department of Public Health (CDPH)				
CDPH, Prop 50 Chapter 3: Water Security	Projects designed to prevent damage to water treatment, distribution, and supply facilities, to prevent disruption of drinking water deliveries, and to protect drinking water supplies from intentional contamination.	Minimum: $5,000 Maximum: $2,000,000 No match required 25% of funds set aside for disadvantaged communities (DACs).	Applications not currently open; the prior pre-application period closed in September 2008. The Universal Pre-application also used for DWSRF was opened until September 21, 2009, but is currently only for Economic Recovery Funds and therefore not open for Prop 50 funds until after September 21, 2009	www.cdph.ca.gov/services/funding/Pages/Prop50.aspx 946-449-5600 mailto:prop50@cdph.ca.gov
CDPH; Prop 50 Chapter 4a1: Small Community Water System Facilities	Grants to small community water systems to upgrade monitoring, treatment, or distribution infrastructure. The water system must be in non-compliance with a safe drinking water standard.			
CDPH, Prop 50 Chapter 4a2: Demo Projects for New Containment Treatment and Removal Technologies	Development and demonstration of new treatment and related facilities for water containment removal and treatment. (Must demonstrate new technology).			
CDPH, Prop 50 chapter 4a3: Community Water Systems Monitoring Facilities	Community water system water quality monitoring facilities and equipment. (Must be in non-compliance with safe drinking water standard).			
CDPH, Prop 50 chapter 4a4: Drinking Water	Source Water protection projects to protect contamination of water supply. Fund may be used for planning, preliminary engineering,			

Program	Brief Description	Key Points	Key Application Dates	Contact Info
Source Protection	detailed design, construction, education, land acquisition, conservation easements; equipment purchase, and implementing the elements of the SWP program.			
CDPH, Prop 50 chapter 4a5: Disinfection Byproduct Facilities	Treatment facilities necessary to meet DBP safe drinking water standard. (Must be in non-compliance with US EPA Stage 1 DBP Rule). If the project is receiving funds under Ch.6, it is not eligible under this chapter.	Minimum: $5,000 Maximum: $10,000,000 No match required. 25% of funds set aside for DACs.		
CDPH, Prop 50 Chapter 4b: Southern California Projects	Projects that assist in meeting drinking water standards and in meeting state's requirement to reduce Colorado River use to 4.4 MAF (Priority ranking based on population, volume of Colorado River water use reduction, and cost/volume saved). This program does not include recycled water.	Minimum: $50,000 Maximum: $20,000,000 1:1 match 25% of funds set aside for DACs. No match required for DACs or small water systems.		
CDPH, Prop 50 Chapter 6b: Containment removal	Containment treatment or removal technology (for Petroleum, NDMA, Perchlorate, Radionuclides, pesticides, heavy metals, pharmaceuticals).	Minimum: $50,000 Maximum: $5,000,000 1:1 match 25% of funds set aside for DACs. No match required for DACs or small water systems.		
CDPH, Prop 50 chapter 6c: UV and Ozone Disinfection	Projects using UV or Ozone Technology. (Must address MCL compliance violation).			
CDPH, Prop 84 Section 75021: Safe Drinking Water Emergency Funding	To fund emergency and urgent actions to ensure that safe drinking water supplies. Eligible projects include, but are not limited to, the following: Providing alternate water supplies including bottled water where necessary to protect public health. Improvements in existing water systems necessary to prevent contamination or provide other sources of safe drinking water including	Minimum 50% cost share Maximum: $250,000 per project	Applications not currently open; the prior pre-application period closed in September 2008. The Universal Pre-application also used for the DWSRF is open until February	www.cdph.ca.gov/services/funding/Pages/Prop84.aspx 916-449-5600 mailto:prop84@cdph.ca.gov

Program	Brief Description	Key Points	Key Application Dates	Contact Info
	replacement wells. Establishing connections to adjacent water system. Design, purchase, installation and initial operation costs for water treatment equipment and systems.		27, 2009, but is currently only for Economic Recovery Funds and therefore not for Prop 84 funds until after February 27, 2009.	
CDPH, Prop 84 Section 75022: Small Community Infrastructure Improvements for Chemical and Nitrate Contaminants	These funds may be used for grants for small community drinking water system infrastructure improvements and related actions to meet safe drinking water standards. Priority shall be given to projects that address chemical and nitrate contaminants, other health hazards and by whether the community is disadvantaged or severely disadvantaged. Special consideration shall be given to small communities with limited financial resources.	Minimum: 50% cost share Maximum: $5,000,000 per project.		
Integrated Regional Water Management (IRWM)				
DWR, Prop 84 chapter 2 & Prop 1E Article 4: Integrated Regional Water Management (IRWM)	Projects that assist local public agencies to meet long-term state water needs, including delivery of safe drinking water, protection of water quality, and protection of the environment. For: Development/Revision of IRWM plans, or Implementation projects of IRWM plans.	$1,000,000M total $900M for Regional allocations North Coast: $37M Sacramento River: $73M San Francisco Bay: $138M San Joaquin River: $57M Central Coast: $52M Tulare Lake: $60M Lahontan: $27M Los Angeles Sub region: $215M Santa Ana Sub region: $114M San Diego Sub region: $91M Colorado River: $36M $100M for inter-regional allocations	All IRWM regions must be approved via the Regional Acceptance Process (RAP) prior to grant application submittal. RAP guidelines are currently in draft form. Original schedule called for RAP applications due in March with Regional acceptance in April 2009. Current schedule is not known.	Norman Shopay (916) 951-9218 mailto:nshopay@water.ca.gov

Program	Brief Description	Key Points	Key Application Dates	Contact Info
		No Maximum grant amount. 25% minimum cost share.	1st round of implantation later in 2009.	
Groundwater				
CDPH, Prop 84 Section 75025: Groundwater Contamination	Grants to prevent or reduce contamination of groundwater that serves as a source of drinking water.	CDPH is currently working on development of these criteria based on Senate Bills SB X2 1 and SB 732 (signed into law on 9/30/08)	Applications not currently open; the prior pre-application period closed on September 2008. But not for Prop 84 funds until after February 27, 2009.	www.cdph.ca.gov/services/funding/Pages/Prop84.aspx 946-449-5600 prop84@cdph.ca.gov
DWR, Prop 84: Local Groundwater Assistance Program	Groundwater studies, groundwater monitoring, groundwater management	Program funds: $6.4M Up to $250,000 per applicant	Next application period expected Spring/Summer 2009.	www.grantsloans.water.ca.gov/grants/assistance.cfm Harley H. Davis 916-651-9229 hdavis@water.ca.gov
SWRCB, Underground Storage Tank Cleanup Fund	Federal and state governmental entities are not eligible for reimbursement from the Fund. This program was created to provide a means for petroleum UST owners and operators to meet the federal and state requirements. The Fund also assists in a large number of small businesses and individuals by providing reimbursement for unexpected and catastrophic expenses associated with the cleanup of leaking petroleum USTs.	$1.5 million less the eligible claimant's applicable level of financial responsibility (or deductible).	Applications accepted on a continuous basis.	www.waterboards.ca.gov/water_issues/programs/ustcf/ 1-800-813-FUND

Program	Brief Description	Key Points	Key Application Dates	Contact Info
Recycled Water				
SWRCB, Prop 13/50: Water Recycling Funding Program-Construction Grants	Grants provided for design and construction of water recycling facilities. All proposed projects must be placed on the SWRCB's WRCP Competitive Project List (CPL) and/or the SRF Priority List to be considered.	25% of the eligible construction cost up to $5M	Applicants accepted on a continuous basis.	www.waterboards.ca.gov/recycling/construction.html Claudia Villacorta 916-341-5735 mailto:cvillacorta@waterboards.ca.gov
SWRCB, Prop 13/50: Water Recycling Funding Program-Construction Grants	Grants are provided for facilities planning studies to determine the feasibility of using recycled water to offset the use of fresh/potable water from state and /or local supplies. Pollution control studies, in which water recycling is an alternative, are not eligible.	50% of eligible costs up to $75,000	Applicants accepted on a continuous basis.	
Storm Water / Stream & Habitat Restoration				
CA State Parks, Prop 1E: Habitat Conservation Fund Program	Eligible funding categories: Deer/Mountain Lion Habitat: Land acquisition Rare, Endangered, Threatened, or Fully Protected Species Habitat: Land acquisition Wetlands Habitat Projects: Acquisition, enhancement, or restoration Anadromous salmonids and Anadromous trout habitat: Acquisition, enhancement, or restoration Riparian habitat: acquisition, enhancement, restoration Trails: acquisition or development of trails Program: Event or series of events intended to bring urban residents into areas with indigenous plants and animals	$2M Available No Min/Max; Recommended maximum $200,000 Required match of 50%	Applications deadline the first work day of October annually. Next application due date: Oct. 2, 2009	www.parks.ca.gov/pages/1008/files/hcf_guide_2007_final_draft_5-15-07.pdf Deborah Viney 916-651-8572 mailto:dvine@parks.ca.gov
CA State Parks: Land and Water Conservation fund	Acquisition or development of lands and facilities that provide or support public outdoor recreation.	No Min/Max; 2007 awards (13) ranged from $30,000 to $210,000 Required match of 50%	Applications deadline generally the first week of March annually. Local	www.parks.ca.gov/?page_id=21360 Betty Ettinger

Program	Brief Description	Key Points	Key Application Dates	Contact Info
		Funds are divided: 60% for SoCal, 40% for NorCal	Agencies: Applicants accepted on a March 2, 2009 State Agencies: June 1, 2009	916-653-7423
CA Wildlife Conservation Board: Various	The Wildlife Conservation Board's three main functions are land acquisition, habitat restoration and development of wildlife oriented public access facilities. Wildlife Conservation Board programs: California Forest Conservation Program (CFCP) California Riparian Habitat Conservation Program (CRHCP) Ecosystem Restoration on Agricultural Lands (ERAL) Habitat Enhancement and Restoration Program (General)		Applications accepted continuously.	www.wcb.ca.gov/Pages/wcb_grant_information.asp Dave Means 9156-445-1095 mailto:dmeans@dfg.ca.gov
DWR, Prop 84 Chapter 4: Feasibility Studies	Conduct feasibility-level investigations of proposed flood risk reduction projects to address short term flood control needs such as levee inspection and evaluation, floodplain mapping and improving the effectiveness of emergency response	$10M in FY 2007-2008 $10M in FY 2008-2009	TBD	www.grantsloans.water.ca.gov/grants/irwm/integregio.cfm Joe Yun 916-651-9222 mailto:DWR_IRWM@water.ca.gov
DWR, Prop 84 Chapter 5: Urban Streams Restoration Program	Eligible uses include: Creek cleanups, eradication of exotic or invasive plants, channel reconfiguration to improve stream geomorphology and aquatic habitat functions, acquisition of parcels critical for flood management, coordination of community involvement of projects. Eligible applicants: local public agencies, non-profit/citizens' groups. Partnership is required.	Program funding: $9M Max/Min per project: $4M / $1M Eligible applicants: local public agencies, non-profit/citizens' groups.	Next round: TBD	www.grantsloans.water.ca.gov/grants/streams.cfm Bill Hoffman 916-651-9626 mailto:whoffman@water.ca.gov
SWRCB, Prop 84: Clean Beaches Initiative Grant	Water quality improvement projects that protect beaches and coastal waters from pollution and toxic contamination, such as sewer collection system improvements or storm water runoff reduction programs.	$90M; to be distributed as follows: $35M to assist local public agencies comply with the discharge prohibition into Areas of Special Biological Significance.	First Round of solicitation closed January 23, 2009; Second round TBD.	http://www.swrcb.ca.gov/water_issues/programs/beaches/cbi_projects/index.shtml

Program	Brief Description	Key Points	Key Application Dates	Contact Info
	Two types of concept proposal applications: implementation projects and research projects	$18M to the Santa Monica bay Restoration Comm. $37M to the Clean Beaches Initiative program. Potential award limits (based on 2007 proposals): $125,000 to $5M 20% matching for projects > $1M 15% match for projects < $1M Matching for DACs waived		Jennifer Toney mailto:jtoney@waterboards.ca.gov 916-341-5646
SWRCB, Prop 84: Storm Water Grant Program	Projects designed to reduce and prevent storm water contamination of rivers, lakes, and streams.	Program funds: $82M Award limits: $5M Solicitations on hold. Future updates will be available.	TBD; No projects have been awarded funding (program on hold).	http://www.swrcb.ca.gov/water_issues/programs/grants_loans/prop84/ Erin Ragazzi 916-341-5733 mailto:eragazzi@waterboards.ca.gov
Federal				
U.S. Army Corps of Engineers-Section 206 Wetland Restoration Grants	For local government projects to restore aquatic ecosystems. Projects are evaluated to determine if they benefit the environment through restoring, improving, or protecting aquatic habitat for plants, fish and wildlife. Proposed projects are also reviewed to determine if they are technically feasible, environmentally acceptable, and provide cost effective environmental benefits. Each project must be complete within itself and not part of a larger project.	Maximum federal expenditure per project is $5M Project costs are shared 65% federal and 35% non-federal.	Continuously soliciting programs to carry out the program objectives	Doug Putnam, Continuing Authorities Program Manager 503-808-4733
USEPA: Targeted Watersheds	Designed to encourage community-based approaches and management techniques to protect and restore watersheds	Unknown future funding	TBD	

Program	Brief Description	Key Points	Key Application Dates	Contact Info
Grant Program				
USEPA, Region 9: Wetland Program Development Grants	Provide eligible applicants an opportunity to conduct projects that promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution.	Total anticipated funding = $1.9M 6 to 15 awards anticipated and likely range from $50k to $350k EPA funding max = 75%	Applications due March 30, 2009	Suzanne Marr 415-972-3468 mailto:marr.suzanne@epa.gov
USBR CALFED Bay Delta		$50M as stated in ARRA	Continuously soliciting programs to carry out the program objectives	
USBR Title XVI	Recycled water feasibility investigations, preliminary engineering studies and research projects. Brackish water desalination is also considered	$126M as stated in ARRA	TBD	www.usbr.gov/lc/socal/titlexvi.html Dennis Wolfe mailto:dwolfe@lc.usbr.gov 951-695-5310
USBR Water Conservation (Previously called Water for America): Plan for our Nations Water Future				
Investigations Program	For planning studies on specific water resource problems conducted by USBR on a geographically defined basis with state, local and federal partners		TBD	www.usbr.gov/wfa/investigate.html http://www.usbr.gov/wci/basin.html William Steele 951-695-5310 mailto:wfa@do.usbr.gov
Basin Study Program	Comprehensive water supply and demand studies to assess the impact of increasing water demands. USBR will work with the state and local partners to initiate and perform 2 to 3 comprehensive water supply and demand studies in the west.	-50/50 cost sharing -2 year duration -to be conducted on major river basins and subbasins		
USBR Water Conservation (Previously called Water for America): Expand, Protect and Conserve our Nation's Water Resources				
Water for America- Water Marketing and Efficiency	For providing funding to implement water conservation and marketing programs (i.e. implement the plan developed under the SOR grant).	Up to $300,000 per project -Minimum 50% non-federal cost share -Completion of project in 2 years	Application period closed 1/14/09; early 2010 next opening	http://www.usbr.gov/wci/

Program	Brief Description	Key Points	Key Application Dates	Contact Info
Grants				William Steele 951-695-5310 mailto:wfa@do.usbr.gov
Water for America- System Optimization Review (SOR) Grants	For studies to evaluate means of saving water via conservation and to develop a plan that includes elements of water conservation, water management, water marketing and preventing conflicts over water.		Application period closed 1/28/09; next applications expected in early 2010	
Water for America- Advanced Water Treatment Grants	For pilot or demonstration projects that will test the viability of advanced water treatment technologies.		TBD	
Water for America- Species of Concern Grants	For planning, design and construction proposals that will benefit federally listed species that are affected by a Reclamation facility or action or that benefit federal recognized candidate species		TBD	
Water Conservation Field Services program	For water conservation and efficiency improvements.	$100,000 max in federal funding per project	TBD	
USBR Water Conservation (Previously called Water for America): Enhance our Nations Water Knowledge (Administered jointly by the USGS and USBR) – To assess water availability, increase new technologies in water planning and management, and to map the geologic and hydrogeologic framework of the Nation's aquifers				
National Streamflow Information Program	Support upgrade of data transmission radios at stream gages and Support regional-scale for selected watersheds and aquifers	$2M available $3M available	TBD; However, the USGS is requesting feedback on the program at http://water.usgs.gov/wsi/stakeholder_feedback.html	Eric Evanson USGS 609-771-3904 mailto:eevenson@usgs.gov
Groundwater Resources Program	To develop and apply methods to enhance the quality of water use information, groundwater data accessibility and undertake regional-scale groundwater studies	$3M available		
National Cooperative	To enhance geologic mapping, geophysics, and hydrogeologic knowledge of regions being	$1.5M available		

Program	Brief Description	Key Points	Key Application Dates	Contact Info
Geologic Mapping Program	studied			
Local				
Metropolitan Water District: Local Resources Program	New and expansion of existing water recycling and groundwater recovery projects. Includes construction of new substantive treatment or distribution facilities. Existing projects or those that have commenced construction prior to application submittal are ineligible.	$250/AF maximum incentive reimbursement (Applications must be made through the applicant's respective Metropolitan member agency).	Project applications will be accepted on an open and continuous basis until the target yield of 174,000AFY is fully subscribed	www.mwdh2o.com/index.htm#grants (middle of page) Andy Hui 213-217-6557 mailto:ahui@mwdh20.com

SEMITROPIC-ROSAMOND WATER BANK AUTHORITY
ANTELOPE VALLEY WATER BANK

M. Rozman[1]
W. Boschman[2]

ABSTRACT

This paper provides an overview of the Antelope Valley Water Bank (AVWB) portion of the Semitropic-Rosamond Water Bank Authority (SRWBA) program. The SRWBA owns and operates two distinct facilities in Kern County, the AVWB near Rosamond and a portion of the Stored Water Recovery Unit (SWRU) within the Semitropic Water Storage District (Semitropic). The SRWBA merges facilities and operations in the SWRU and the AVWB to provide the following combined water bank capacities:

- **Storage-** 800,000 acre-feet (AF) Firm; plus, up to 350,000 AF on a when available basis
- **Recharge-** 133,000 AF/Yr Firm; plus, up to 430,000 AF/Yr on a when available basis
- **Recovery-** 200,000 AF/Yr Firm; plus, up to 287,000 AF/Yr on a when available basis

The AVWB, located in the west end of the Antelope Valley, South-Central California, has been in development since 2001. In September 2006, Kern County certified the EIR. The project recharges water into storage using recharge basins and will use new and existing wells to recover water for delivery into local and regional conveyances. The project is modular by design and is being constructed in phases. The first phase was constructed in 2008. Work is now proceeding on the next phases, Phases 1B and 1C, to increase recharge capacity and add recovery wells. When fully developed, the facilities will consist of recharge basins, recovery wells, collection/distribution pipelines, pumping stations and storage tanks. When completed the AVWB component of the combined water bank will have the following capacities:

Total Storage Capacity	500,000 AF
Recharge Capacity	Up to 100,000 AF/yr (350 cfs)
Recovery Capacity	Up to 100,000 AF/yr (250 cfs)

INTRODUCTION

The Semitropic-Rosamond Water Bank Authority (SRWBA) was formed by Semitropic Water Storage District (Semitropic), Rosamond Community Services District (RCSD), and Valley Mutual Water Company (Valley Mutual) as a Joint Powers Authority (JPA), as defined under California Government Code Section 6500, et. seq. The SRWBA

[1] Vice President, Chief Civil Design Engineer, GEI Consultants, Bookman-Edmonston Division, Glendale, CA; mrozman@geiconsultant.com
[2] General Manager, Semitropic-Rosamond Water Bank Authority, Wasco, CA

provides water bank participants (Customers) a diversity of assets, operational flexibility, and water supply reliability. The SRWBA merges capacity in the Semitropic Stored Water Recovery Unit (SWRU) and the Antelope Valley Water Bank (AVWB) to provide the following capacities:

- **Storage**- 800,000 acre-feet (AF) Firm; plus, up to 350,000 AF on a when available basis
- **Recharge**- 133,000 AF/Yr Firm; plus, up to 430,000 AF/Yr on a when available basis
- **Recovery**- 200,000 AF/Yr Firm; plus, up to 287,000 AF/Yr on a when available basis

The SWRU and AVWB are located in different areas of Kern County which provides for the operational flexibility for the Customers. This paper presents the existing and planned facilities of the AVWB.

ANTELOPE VALLEY WATER BANK — PROJECT INFORMATION

The AVWB, located in the west end of the Antelope Valley as shown in Figure 1, has a storage capacity of 500,000 AF. Water for recharge and storage in the AVWB will be delivered via the East Branch of the California Aqueduct, which is part of the CA State Water Project (SWP).

When needed, stored water will be recovered for delivery via a series of recovery wells and collection piping that will connect to local and regional conveyances, such as returning recovered water back to the California Aqueduct. The project currently has up to 11,000 AF/yr of recharge capacity with an additional 11,000 AF/yr under design. Direct recharge will be accomplished by up to 1,500 acres of recharge basins. A recovery yield of up to 100,000 AF/yr will be provided by approximately 43 existing and new wells that will deliver supplies to the Antelope Valley East Kern Water Agency (AVEK) West Feeder (for exchange), and the California Aqueduct. The first phase of recovery facilities are scheduled to come online by December 2010, with capacity ramping up from 25,000 AF/yr to 100,000 AF/yr as needed there-after.

The AVWB has been in development since 2001. A comprehensive Feasibility Study was performed from 2002 through 2005. This was followed by a 12-month pilot test to further quantify performance, including percolation rates and water quality impacts. The test was performed in consultation with Los Angeles County Waterworks District #40 (LA County #40) and the United States Geological Survey (USGS). Test results have met or exceeded all project requirements, indicating long term recharge rates of over 0.8 feet/day with applied water reaching the water table in less than 3 months.

Kern County certified the Final EIR on September 12, 2006. The CEQA documentation covers all construction and operational aspects of the AVWB. The important characteristics of the AVWB are listed in Table 1. The Final EIR includes water agencies in most of southern California as a potential place of use for water recovered from the project. Each potential customer will be responsible for environmental documentation for their use of the water bank.

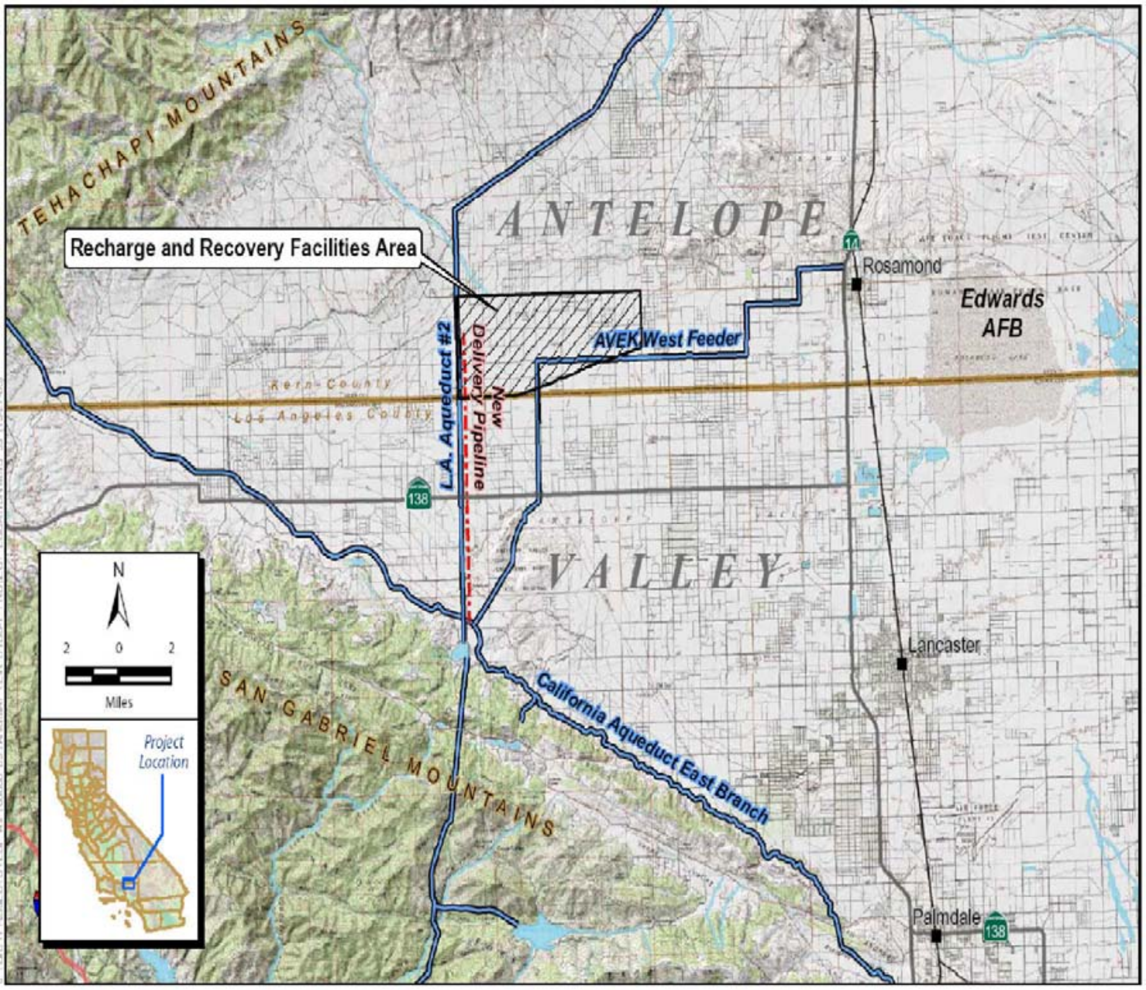


Figure 1. Antelope Valley Water Bank Location Map

Table 1. Important Characteristics of the AVWB

Item	Characteristics
Source of Recharge Water	Surface supplies delivered via the CA Aqueduct
Total Storage Capacity	500,000 AF
Recharge Capacity	Up to 100,000 AF/yr (350 cfs)
Recovery Capacity	Up to 100,000 AF/yr (250 cfs)
Overdraft Recovery	10% of recharged water left behind for overdraft recovery

The AVWB is modular by design. Facilities can be added in increments as needed (with the exception of the Phase 2 pipeline, see below). Phase 1A, which consisted of initial recharge basins was completed in June 2008, demonstrated that the SRWBA is capable of designing, permitting, bidding, contracting, and constructing a module of the project within 6 months on-budget. Later phases will benefit significantly from the templates that were developed for Phase 1A. Contract documents are proceeding for a portion of Phase 1B and 1C to increase recharge capacity and add recovery wells. Phase 1 is dependent on availability of wheeling capacity in Antelope Valley East Kern Water Agency (AVEK) infrastructure, which may vary with time. As these wheeling agreements are being prepared with AVEK, Phase 2 is being pursued which entails construction of facilities that allow recharge and recovery independent of AVEK. Phase 2 will be accomplished through construction of a new 72-inch ID, 8.25 mile, bi-directional pipeline from the AVWB to the East Branch of the California Aqueduct to allow delivery of SWP water. Design work is also proceeding on this phase of the project. As indicated above, the Phase 2 pipeline is the only element of this project that is not modular.

Facilities

When fully developed, the facilities will consist of recharge basins, recovery wells and conveyance facilities consisting of pipelines and pumping stations. Figure 2 shows the Site Plan for the Recharge and Recovery Facilities.

Recharge Basins The AVWB is on very sandy, gently sloping farm land. Recharge basins step down across the terrain through 3- to 5-foot high berms in a fashion similar to rice paddies. This innovative approach minimizes costs and air impacts due to earthwork, allows operations to be adjusted quickly, and permits organic farming between recharge seasons. Project lands provide long term recharge rates of at least 0.8 feet/day with many basins anticipated to support more than 1 foot/day. Recharged supplies reach the water table within three months. Phase 1A, already constructed and operational, includes 126 acres of recharge basins. Phase 1B will add 160 acres of basins, with additional modules being added as required up to an estimated total of 800 acres (1,500 acres available). Future recharge basin construction will be facilitated by templates developed during Phase 1A. During the EIR process, Kern County relinquished all county road easements within the AVWB property, allowing facilities to be sized and placed without hindrance from County road requirements.

Recovery Wells The recovery system can be scaled up in increments as required. The project includes 10 existing wells with over 30 third-party wells that may be available. There are plans for up to 43 new wells equipped with 300 to 400 HP electric motors. Wells will generally be installed in groupings of ten to maximize the economies of scale associated with procurement and installation. New wells will average 700 feet deep with 20-inch steel casing and approximately 300 feet of screening. The Southern California Edison (SCE) method of service study concluded that Phase 1C recovery capacity can be accommodated by the existing well grid. At full-scale recovery of 250 cfs, SCE concluded that the Project will require either upgrades to the Neenach and Rosamond Substations or a new dedicated 66 KV sub-transmission service. An alternate method of service study was performed by the Southern California Gas Company, which concluded that it could power Phase 2 booster pumps using natural gas. The SRWBA is preparing contracts for installation of recovery wells on third-party lands, using templates that Semitropic has developed and used for hundreds of wells at the Semitropic Water Bank.

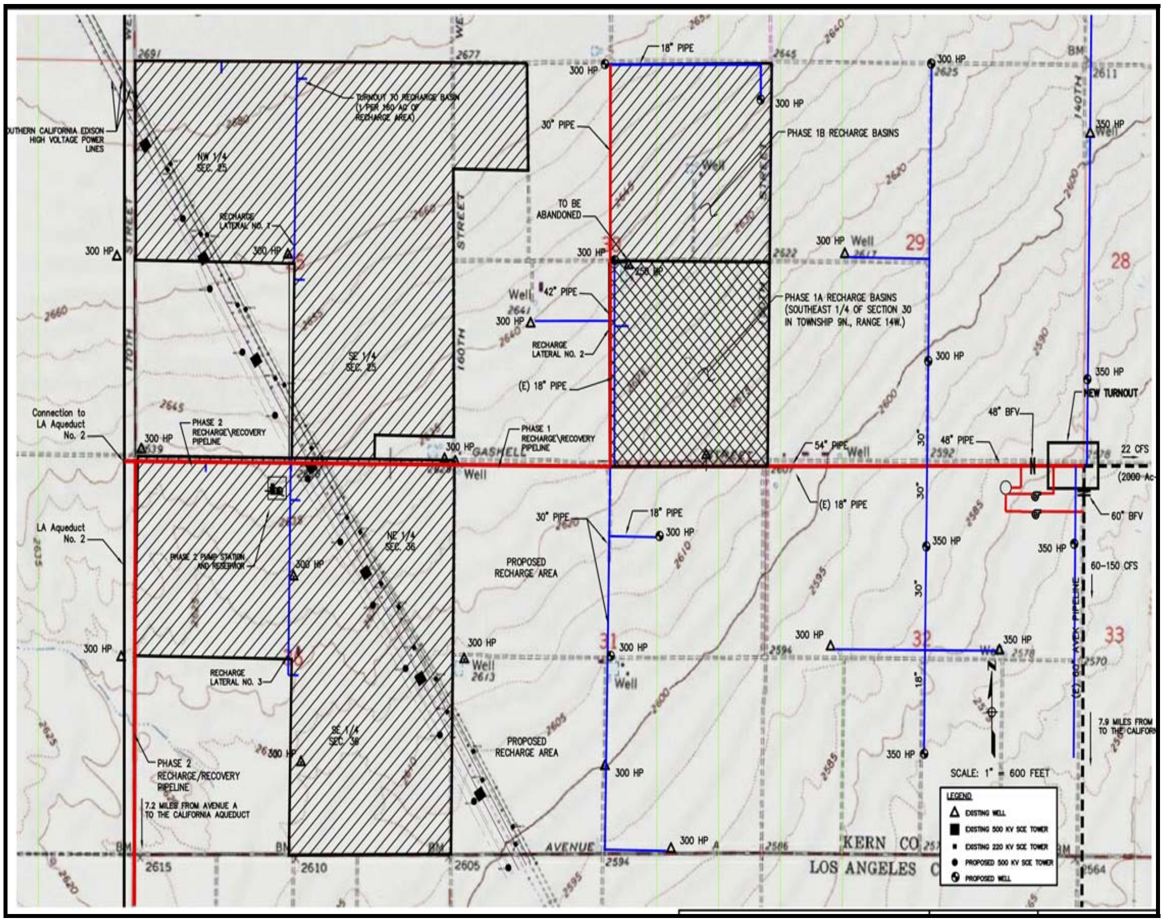


Figure 2. Antelope Valley Water Bank Facilities Layout

<u>AVEK West Feeder</u> The West Feeder is a buried steel pipe owned and operated by AVEK to convey raw SWP water from Turnout 20A on the East Branch of the California Aqueduct downhill for delivery to farmers (including the AVWB lands), RCSD, the City of Mojave, California City, Edwards Air Force Base, Boron, and industrial customers. The pipeline varies from 48- to 60-inch in diameter upstream of the AVWB and is 36-inch downstream of the AVWB. The pipeline has a capacity of approximately 150 cfs (in the 48- and 60-inch reaches). AVEK currently uses up to approximately 34 cfs of this capacity during heavy demand periods. This demand will increase as AVEK implements various projects that will tie the West Feeder to additional service areas. The AVWB currently receives West Feeder water through Turnout 9.0LB, which ties to an 18-inch ID, project owned, buried steel pipeline that feeds the Phase 1A recharge basins and additional project lands to the west. Water in the West Feeder is under sufficient pressure to enable delivery to all AVWB lands without lift stations.

<u>Phase 2 pipeline</u> The EIR allows for installation of a 8.25-mile, 72-inch, buried, steel pipeline to operate bi-directional from the AVWB, south to the California Aqueduct East

Branch. Phase 2A entails construction of a new turn-in/turn out and pipeline from the East Branch for up to 311 cfs of gravity recharge of SWP water independent of AVEK. Phase 2B entails construction of power infrastructure and a lift station for 200 cfs of recovery back to the East Branch independent of AVEK. Phase 2C entails installation of additional recovery wells as needed to bring the project up to full capacity. Working with the East Branch owner, the Calfornia Department of Water Resources (DWR), AVWB started the new turn-in/turn-out process in October 2008, and the SRWBA stands ready to authorize detailed design. The majority of the pipeline alignment is within an existing easement for a water pipeline that was never built. The team is finalizing negotiations with the owner of this easement for use by the AVWB.

Power supplies and Capital Cost Opportunities SCE has concluded that Phase 1C recovery systems (up to 60,000 AF/yr) can be served by existing power infrastructure. However, Phase 2 recovery (up to 100,000 AF/yr) will require transmission and substation upgrades. Alternately, the AVWB has been in discussions with a solar company to locate a 140 MW project on project land, as part of a larger 240 MW project, with the intent of connecting to the planned adjacent SCE Whirlwind substation that is part of the Tehachapi renewable transmission project. It may be feasible for the AVWB to use power from the solar project for water bank recovery operations and export the excess power at other times. This arrangement could dramatically reduce power infrastructure capital costs carried by the project.

The AVWB offers opportunities for hydroelectric power generation. The Phase 2 pipeline would deliver water downhill from the East Branch under at least 140 psi of pressure that would also need to be dissipated. Analyses indicate that up to 5 MW could be generated. SCE indicates that this type of operation would be eligible for enrollment in the California Renewable Energy Small Tariff (CREST) program, which is exempt from the normal SCE procurement and the California Energy Commission (CEC) permitting processes and could be contracted in a matter of months. Semitropic has extensive experience developing renewable power as a component of its water banks. The district has constructed over 55 miles of transmission lines, a 979 kW solar array, and a 1 MW hydroelectric generator.

Monitoring and operational control RCSD has been designated to operate the AVWB due to its proximity and experience with similar stormwater ponds, wells, pipelines, and telemetry. Phase 1A has been equipped with water level telemetry systems, a remote access weather station, turnouts with totalizing flow meter, piezometers, and monitoring wells to ensure that operations are adequately controlled.

Table 2. AVWB Facilities Summary

Item	Specifications
Pipeline conveyance	**Phase 1A (existing):** 18-inch, steel pipeline one mile from Turnout 9.0LB on the AVEK West Feeder, providing up to 11,000 AF/yr (15 cfs) of recharge capacity.
	Phase 1B (by December 2010): Enlargement of West Feeder Turnout 9.0LB and associated pipeline to 48-inch, for a total up to 70,000 AF/yr (100 cfs) of recharge.
	Phase 2A: Construction of an 8.25 mile, 72-inch, steel pipeline from the East Branch, providing up to 100,000 AF/yr (311 cfs) of recharge capacity.
Recharge Basins	**Phase 1A (existing):** 126 acres of basins, providing at least 43 cfs of recharge capacity
	Phase 1B (by December 2010): 160 acres of basins, providing at least 101 cfs of capacity.
	Phase 2A: 515 acres of additional basins, providing at least 350 cfs of recharge.
	Phase 1C first stage (by December 2010): Upgrade of eight existing wells and installation of six new wells, providing at least 34 cfs of recovery capacity.
Recovery Wells	**Phase 1C second stage:** Add up to nine new wells (15 total), providing a total of 94 cfs of recovery capacity.
	Phase 2B-2C: Up to 28 additional new wells (43 total) installed as required to meet recovery requirements, providing up to 250 cfs of recovery capacity.
Recovery Wells	**Phase 1C, first stage:** Installation of a 300,000 gal regulation tank, and controls for up to 25,000 AF/yr (34 cfs) of return into the West Feeder for delivery to downstream AVEK customers in exchange for SWP water in the California Aqueduct.
Conveyance of Recovered Water	**Phase 1C, second stage:** Installation of a 1750 HP pump station, a 1950 HP booster station, and controls on the West Feeder for pump-back to the East Branch, for an additional 35,000 AF/yr (60 cfs) of recovery (total of up to 60,000 AF/yr, 94 cfs).
Conveyance of Recovered Water	**Phase 2B:** Construction of power infrastructure, a 13,000 HP pump station, and a 1 MG regulating reservoir to pump-back into the new Phase 2A pipeline, providing up to 100,000 AF/yr (200 cfs) of recovery capacity to the East Branch.

Operations

The AVWB will receive water from the California Aqueduct's East Branch. Water will be recharged through basins and recovered to the AVEK West Feeder and the California Aqueduct for direct delivery or exchange.

Conveyance and Recharge of Water into Storage at the AVWB

Water may be recharged at the AVWB whenever desired, with no permit restrictions regarding the time of year. The downhill run from the East Branch to the AVWB allows recharge under gravity. Phase 1 entails up to approximately 100 cfs of flow through the AVEK West Feeder. However, AVEK is pursuing its own conjunctive use projects, and it is possible that wheeling capacity in the West Feeder will diminish over time. Therefore, Phase 2 entails development of facilities that are independent of AVEK.

The AVWB is permitted to recharge up to 100,000 AF per year. Testing indicates that 100,000 AF could be recharged in less than three months at full build-out. While the EIR allows for up to 1,500 acres of basins, testing indicates that only approximately 800 acres will be required, providing potential expansion capacity if appropriate. Recharge will occur primarily during the winter - spring when water is most abundant, but recharge could occur at any time of the year.

Recovery Capacity and Conveyance

Water may be recovered from the AVWB whenever desired, with no permit or contract restrictions regarding the time of year. When needed, stored water will be recovered using wells to provide up to 250 cfs of recovery capacity. The recovered water will be delivered back to the California Aqueduct' East Branch or into AVEK's system (for exchange). During the first stage of Phase 1C, up to 34 cfs will be delivered into the AVEK service area in exchange for SWP entitlement. During the second stage of Phase 1C up to 60 cfs would be pumped back up the West Feeder for direct delivery to the East Branch, providing a total of 94 cfs of recovery capacity through the AVEK system. Phase 2B will entail construction of a pump station, regulation reservoir, and controls for recovery independent of AVEK, through a new Phase 2 pipeline (at least 200cfs) to the East Branch. Within the defined recovery area, there are numerous existing irrigation wells that might be tied to the AVWB through contracts with land owners. This approach provides numerous benefits through shared maintenance costs and outreach. Semitropic has successfully entered into hundreds of these contracts in their water banking program.

SUMMARY

The AVWB, in development since 2001, recharges water into storage using recharge basins and will use new and existing wells to recover water for delivery into local and regional conveyances. The project is modular by design and is being constructed in phases. Following a successful EIR process, the first phase was constructed in 2008. Work is now proceeding on the next phases, Phases 1B and 1C, to increase recharge capacity and add recovery wells. When fully developed, the facilities will consist of recharge basins, recovery wells, collection and distribution pipelines, pumping stations and storage tanks. Once completed, the AVWB component of the combined water bank will have the following capacities:

Total Storage Capacity	500,000 AF
Recharge Capacity	Up to 100,000 AF/yr (350 cfs)
Recovery Capacity	Up to 100,000 AF/yr (250 cfs)

IRRIGATING ALFALFA WITH LIMITED WATER SUPPLIES

Blaine Hanson[1]
Steve Orloff[2]
Khaled Bali[3]
Blake Sanden[4]
Dan Putnam[5]

ABSTRACT

The evapotranspiration (ET) of fully-irrigated alfalfa ranges from 31.9 inches in northern California to 65.2 inches in the low desert areas of southern California. During low water years, however, ET may be reduced by limited amounts of applied water. Strategies for coping with limited water supplies include reducing the irrigated acreage (Strategy 1), fully-irrigating the earlier harvest periods until the water supply is used up and then no irrigation thereafter (Strategy 2), and deficit irrigate the field for the entire season by reducing the water applications between harvests (Strategy 3). An evaluation showed slight differences in returns to land and management between the first two strategies. The third strategy could not be adequately evaluated because of the lack of both cost data and yield-ET relationships under deficit irrigation.

INTRODUCTION

Alfalfa is California's single largest agricultural water user due to the amount grown, typically about 1 million acres, and its long growing season. Seasonal alfalfa water applications generally range from 4,000,000 to 5,500,000 acre-feet.

The evapotranspiration (ET) of fully-irrigated alfalfa measured in commercial fields ranges from 31.9 inches in northern California to 65.2 inches in the low desert areas of southern California. Drought conditions can reduce ET to levels smaller than needed for maximum yield due to limited water supplies. Several strategies are available for alfalfa growers to cope with a reduced water supply, but the bottom line is that yields will be reduced compared to normal water supply conditions.

[1] Irrigation and Drainage Specialist, Department of Land, Air and Water Resources, One Shields Ave., University of California, Davis; brhanson@ucdavis.edu)
[2] UCCE Farm Advisor, Siskiyou County, 1655 South Main Street, Yreka, CA 96097; sborloff@ucdavis.edu
[3] UCCE Farm Advisor, Imperial County, 1050 East Holton Road, Holtville, CA 92250; kmbali@ucdavis.edu
[4] UCCE Farm Advisor, Kern County, 1031 South Mount Vernon Avenue, Bakersfield, CA 93307; blsanden@ucdavis.edu
[5] Forage Specialist, Department of Plant Sciences, One Shields Ave., University of California, Davis; dhputnam@ucdavis.edu

PROCEDURES

During the past five years, alfalfa ET and yield were measured in California in commercial fields located in the Imperial Valley, southern part of the San Joaquin Valley, Sacramento Valley, and the Intermountain Area of northern California (Scott Valley, near Yreka, CA and Tulelake, south of Klamath Falls, OR). These data provided a basis for evaluating strategies for irrigating alfalfa with limited water supplies. ET was determined at these sites using eddy covariance and surface renewal energy balance methods. At each site, ET and yield was measured for fully-irrigated alfalfa and for alfalfa subjected to mid-summer deficit irrigation (no irrigation).

RESULTS

Evapotranspiration

Daily evapotranspiration of alfalfa was small, generally between 0.05 and 0.1 inches per day, at the start of the crop growing season, the time of which varied depending on climate characteristics, increased with time of year to maximum values between 0.3 and 0.4 inches per day in June/July, and then decreased to small values at the end of the crop season (Figure 1). For each harvest cycle, small ET values occurred just after harvest, and then increased rapidly to maximum values after the first irrigation between harvests. Seasonal evapotranspiration ranged from 31.9 inches (Scott Valley 2008) to 65.2 inches (Imperial Valley 2008) (Table 1).

Yield – ET Relationships

Cumulative yield of the fully-irrigated alfalfa increased linearly with cumulative ET during the crop season at all sites except for the Imperial Valley (Figure 2). The effect of heat stress on yield during the later part of summer is believed to have caused the Imperial Valley behavior.

Strategies for Irrigating Alfalfa with Limited Water Supplies

Strategies for coping with limited water supplies include:

Strategy 1. Reduce the irrigated acreage

- ♦ Fully irrigate the reduced acreage for the crop season to obtain maximum yield over the reduced acreage.
- ♦ The amount of acreage reduction depends on the amount of available irrigation water.
- ♦ No irrigation occurs on the remaining acreage, which will result in a yield loss.
- ♦ No field-wide yield reduction may occur for the first harvest provided sufficient soil moisture from winter/spring snowmelt or rainfall exists. This condition may frequently occur in the Intermountain Region and the Sacramento Valley even during conditions of drought, but may not occur in the alfalfa production areas of southern California.

♦ The critical irrigation is the first irrigation after harvest, which should occur as soon as possible.

Strategy 2. Fully irrigate earlier harvests; no irrigation for the remaining harvests.

♦ Fully irrigate the entire field staring with the first harvest period until the water supply is used up.

♦ No irrigation will occur for the rest of the crop season, resulting in a yield loss.

♦ The number of earlier harvests that can be fully irrigated depends on the amount of available irrigation water.

♦ This strategy will maintain the high yields of the early harvests and will result in no irrigation during the later part of the crop season during which yields and quality normally are smaller compared to the earlier harvests.

♦ The critical irrigation is the first irrigation after a harvest.

Strategy 3. Deficit irrigate the entire field during the crop season.

♦ Irrigate the entire field during the crop season with a reduced amount of irrigation water applied per harvest period.

♦ Approaches for reducing the irrigation water per harvest period include applying smaller water applications per irrigation, reducing the number of irrigations per harvest period, or a combination of both. Applying smaller water applications per irrigation is appropriate for sprinkle irrigation, but not for flood irrigation. Reducing the number of irrigations can be used by both sprinkle and flood irrigators.

♦ Yield loss will occur over the entire field, but the amount of yield loss will depend on the reduction in applied water and the relationship between alfalfa yield and ET under deficit irrigation.

♦ No yield reduction may occur for the first harvest provided sufficient soil moisture from snowmelt/rainfall exists, depending on location.

Which Strategy is the Best?

The best strategy is the one that provide the largest returns to land and management for the irrigator, which will depend on the revenue reduction due to reduced yield and the production costs of a particular strategy. Variable production costs include irrigation costs and harvest costs. Variable production costs per acre per harvest will be the same for Strategy 1 as for a fully irrigated field, but because part of the field will not be irrigated, the field-wide production costs will be smaller than those normally incurred. Variable production costs per acre per harvest of Strategy 2 will be the same as those of a fully-irrigated field for the harvests that are fully-irrigated, but no variable costs will occur during the no-irrigation period. Production costs may be reduced for Strategy 3 because of smaller yields per acre per harvest, but the entire field will be harvested. Irrigation and harvest costs per acre should be smaller than those of a fully-irrigated field, but no information exists on the actual costs of a deficit-irrigated field. It should be noted that fixed costs will not change due to a particular strategy. Also, fertilizer and pest control costs may not change since these costs generally occur early in the crop season.

The returns to land and management were evaluated for the first two strategies using the relationships in Figure 2 and alfalfa production cost data for commercial fields found at "http://alfalfa.ucdavis.edu/+producing/index.aspx?/cat=Economics and Marketing", for Scott Valley, Sacramento Valley, and the southern San Joaquin V alley. The economic analysis was not conducted for the Imperial Valley site because the production costs were not in a format that was usable for this study. Crop prices of $100 per ton and $200 per ton were also used. Total costs included the production costs and cash overhead costs (taxes, insurance, etc.). Non-cash costs (depreciation) were not included (recommended by R. Howitt, chair of the Department of Agricultural Economics, University of California, Davis). Note that the Tulelake data were not used for this analysis because little yield differences occurred between deficit irrigated and fully irrigated alfalfa at that site because of crop water use of shallow ground water.

Little difference in returns to land and management were found between Strategies 1 and 2 (Figures 3, 4, 5, and 6). Differences were the largest for small amounts of ET and decreased as the ET increased. In some cases, strategy 1 was more profitable than strategy 2, while in other cases, the opposite occurred. Negative returns occurred for a crop price of $100 per tons until the available water was sufficient to supply 69 to 79% of the ET for the Sacramento Valley and San Joaquin Valley (40% for Scott Valley). However, for the Sacramento Valley 2008, negative returns occurred regardless of the amount of available water. At $200 per ton, positive returns occurred for water supplies that could meet at least 31 to 50% of the fully-irrigated ET for the Sacramento Valley, 16 to 25% for the San Joaquin Valley, and 14 to 28% for Scott Valley. Little difference in the minimum ET was found between strategies. However, considerable differences occurred between Sacramento Valley 2007 (31 to 39 %) and 2008 (48 to 50%) (same field for both years), reflecting the higher yield-ET relationship of 2007 compared to 2008 (fig. 2). Smaller differences occurred between the San Joaquin Valley 2007 (23 to 25%) and 2008 (16 to 24%), which had similar yield-ET behavior.

Numerous studies have shown that yield is linearly related to ET for deficit-irrigation conditions, but these relationships are site-specific. Thus, for Strategy 3, a 50% reduction in ET generally will decrease yield by 50%; however, uncertainty exists concerning the actual yield for a given amount of ET and in the effect of this yield on variable costs since the entire field must be irrigated and harvested. One consideration is that for small amounts of applied water per harvest, yield per acre per harvest under Strategy 3 may be uneconomical to harvest. A yield of 0.5 tons per acre generally is considered to be a threshold yield for determining if it is economical to harvest.

CONCLUSION

Strategies for irrigating alfalfa with limited water supplies include reducing the fully-irrigated acreage to reflect the reduced water supply (Strategy 1); fully-irrigating the earlier harvest periods as long as possible and then terminating irrigation for the remainder of the crop season (Strategy 2); and deficit irrigating the entire field for the crop season by applying less water between harvests (Strategy 3). Yield-ET data for fully-irrigated alfalfa developed at various locations in California were used to evaluate the economics of the first two strategies. Economics of Strategy 3 could not be completely determined because of the lack of data on yield and costs under deficit irrigation conditions. The evaluation showed little differences in returns to land and management between the first two strategies. The minimum amount of available water needed for positive returns depends on crop price, seasonal yield/ET relationships, and production costs.

Based on these results, Strategy 2 is recommended for irrigating alfalfa with limited water supplies. One advantage of the Strategy 2 is that it better guarantees using all of allocated water by applying the water during the earlier part of the crop season. Strategy 1 runs the risk of losing water allocations due to additional water reductions later in the crop season. The effect of Strategy 2 on crop ET and yield is illustrated in Figure 7 for Sacramento Valley 2007, where sufficient water was available to supply about 50% of the fully-irrigated ET. No irrigations occurred after the end of June (day of year 180). The no irrigation period reduced ET and yield; however, yields of the following year appeared to recover, based on the yield of the first harvest of 2008.

Table 1. Measured and historical seasonal ET of the fully-irrigated alfalfa at various locations in California. The historical ET was obtained from publications of state and federal agencies in California, but little or no published research supporting the historical values appears to exist.

Site	**Year**	**Measured seasonal ET (inches)**	**Historical seasonal ET (inches)**
Imperial Valley	2007 2008	57.4 65.2	76
San Joaquin Valley	2007 2008	56.6 59.8	49
Sacramento Valley	2005 2006 2007 2008	50.5 54.4 55.0 50.3	48
Scott Valley (Etna)	2007 2008 2009	38.9 31.9 35.9	33
Scott Valley (Fort Jones)	2009	40.9	33
Shasta Valley	2009	40.7	33
Tulelake	2007 2008	39.9 37.9	33

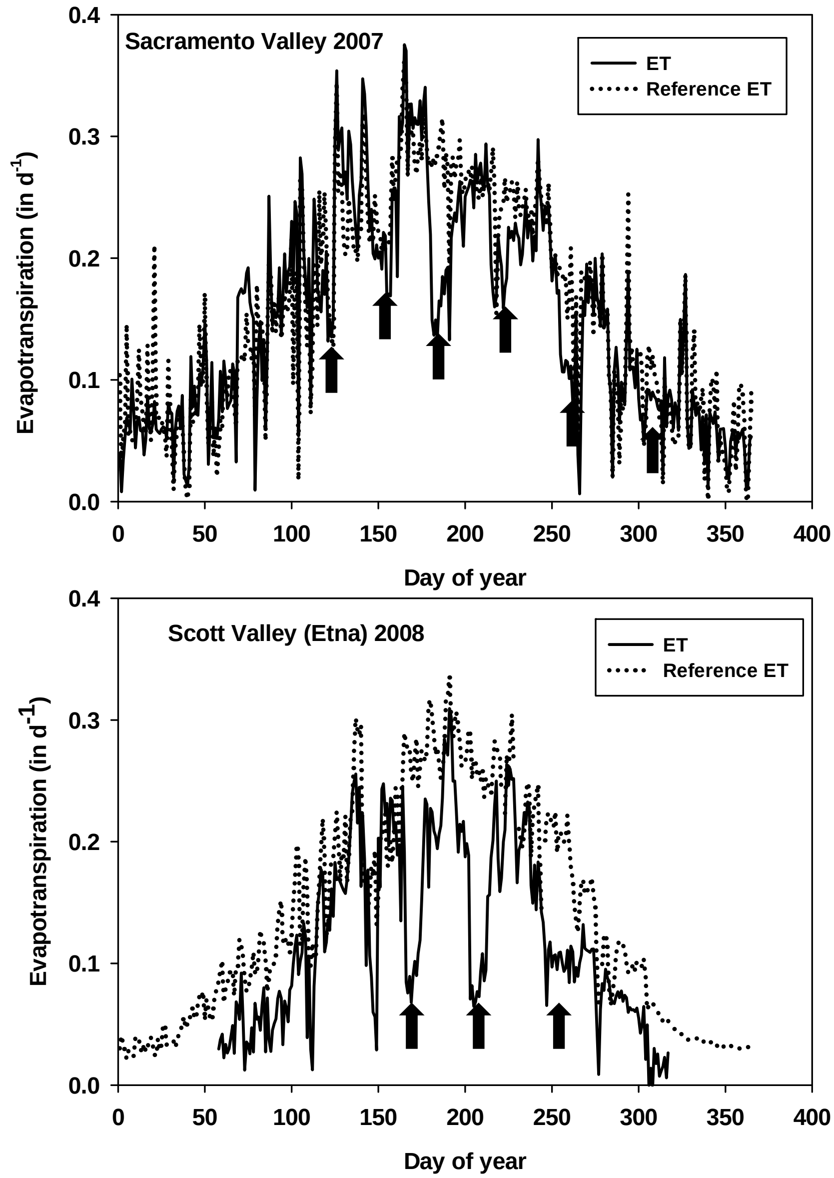


Figure 1. Evapotranspiration of alfalfa for the Sacramento Valley (2007) and Scott Valley (2008). The reference ET is that obtained from the California Irrigation Management Information System. The arrows show the harvest times.

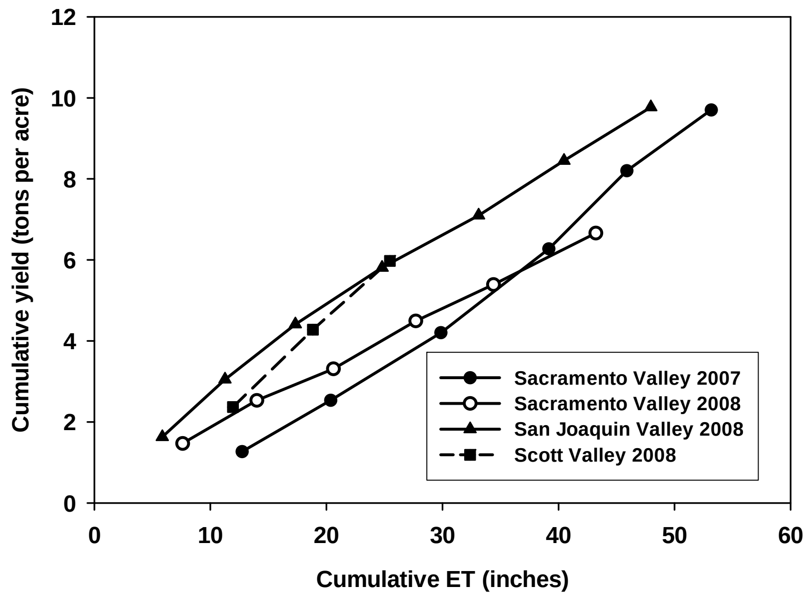


Figure 2. Relationships between cumulative evapotranspiration (ET) and cumulative yield for fully-irrigated alfalfa for three locations in California.

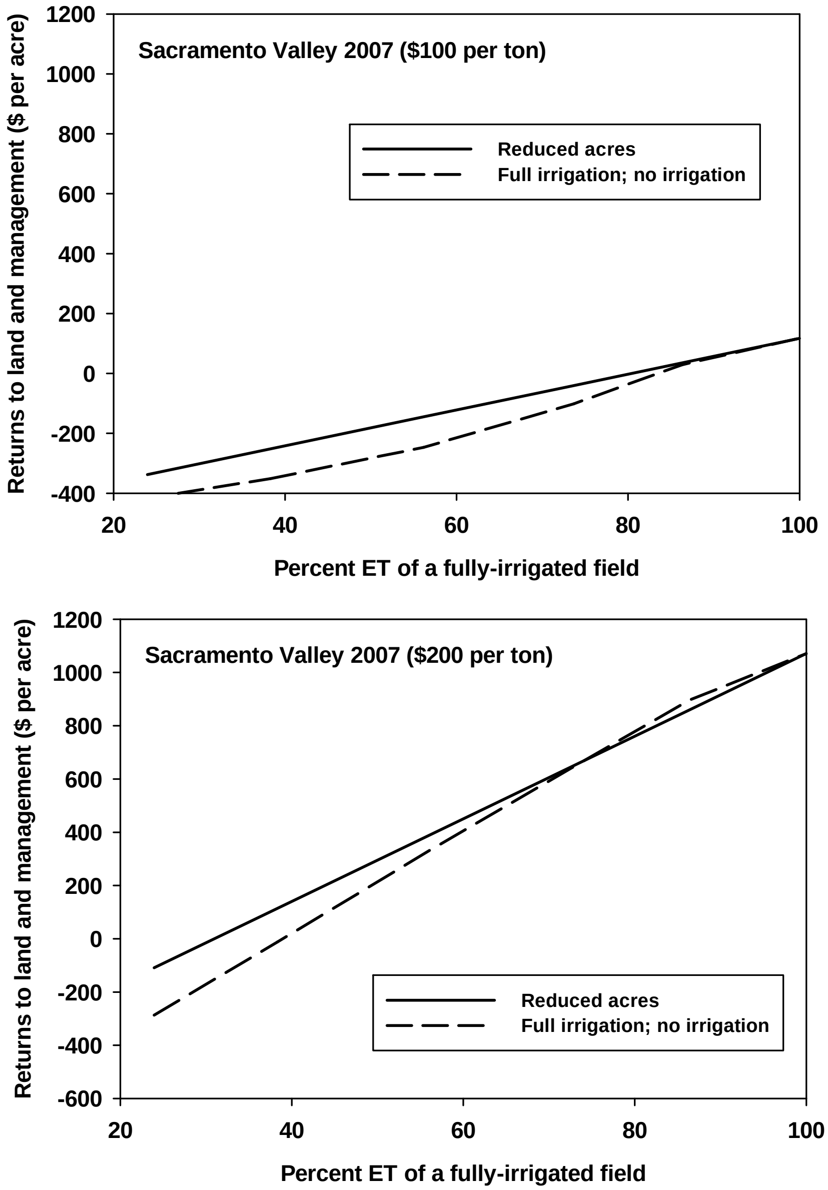


Figure 3. Effect of Strategies 1 and 2 and crop price on the returns to land and management for the Sacramento Valley 2007 site. Six harvests occurred at this site.

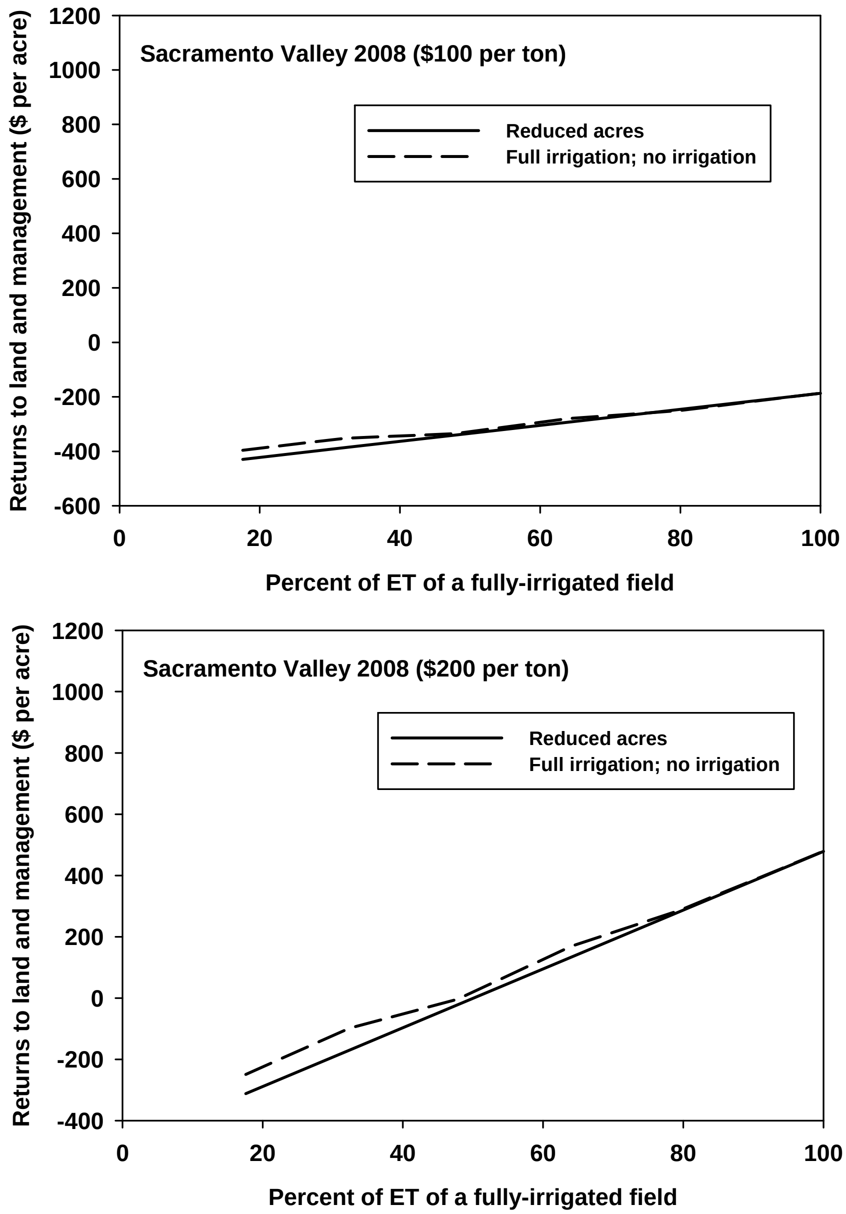


Figure 4. Effect of Strategies 1 and 2 and crop price on the returns to land and management for the Sacramento Valley 2008 site. Six harvests occurred at this site.

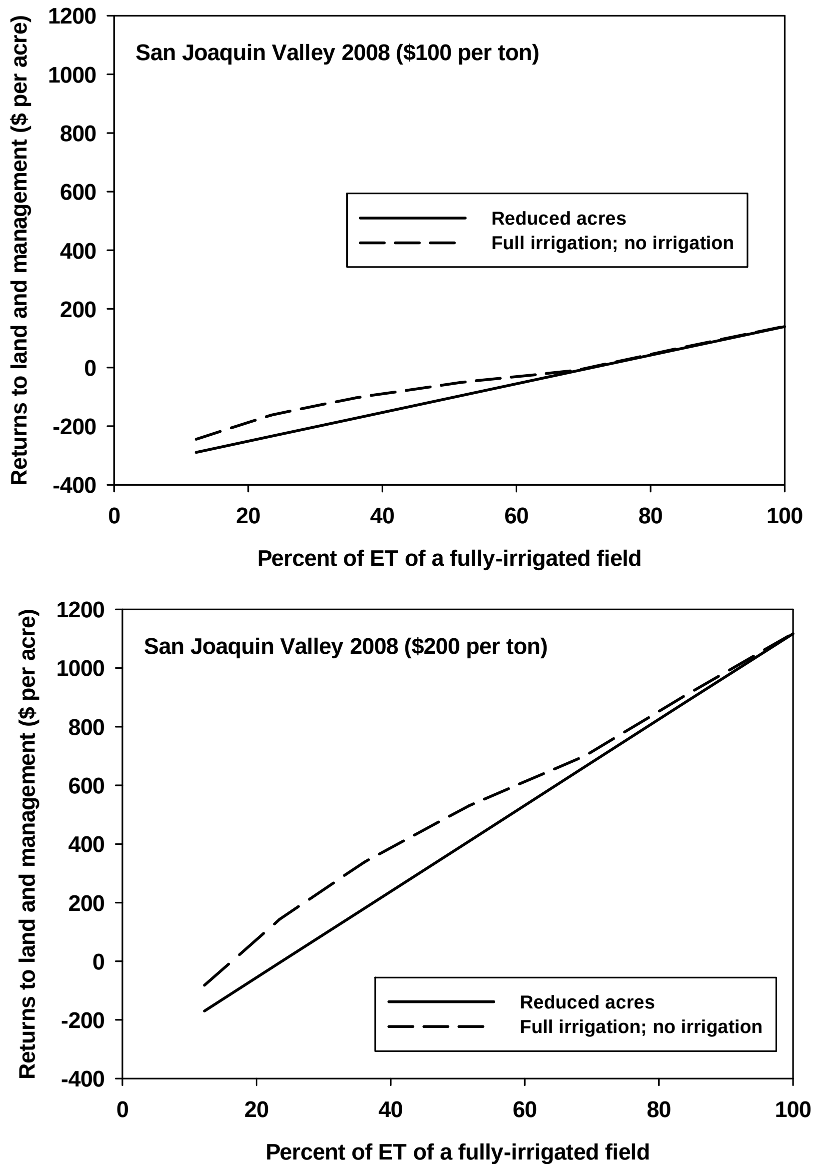


Figure 5. Effect of Strategies 1 and 2 and crop price on the returns to land and management for the San Joaquin Valley 2008 site. Seven harvests occurred at this site.

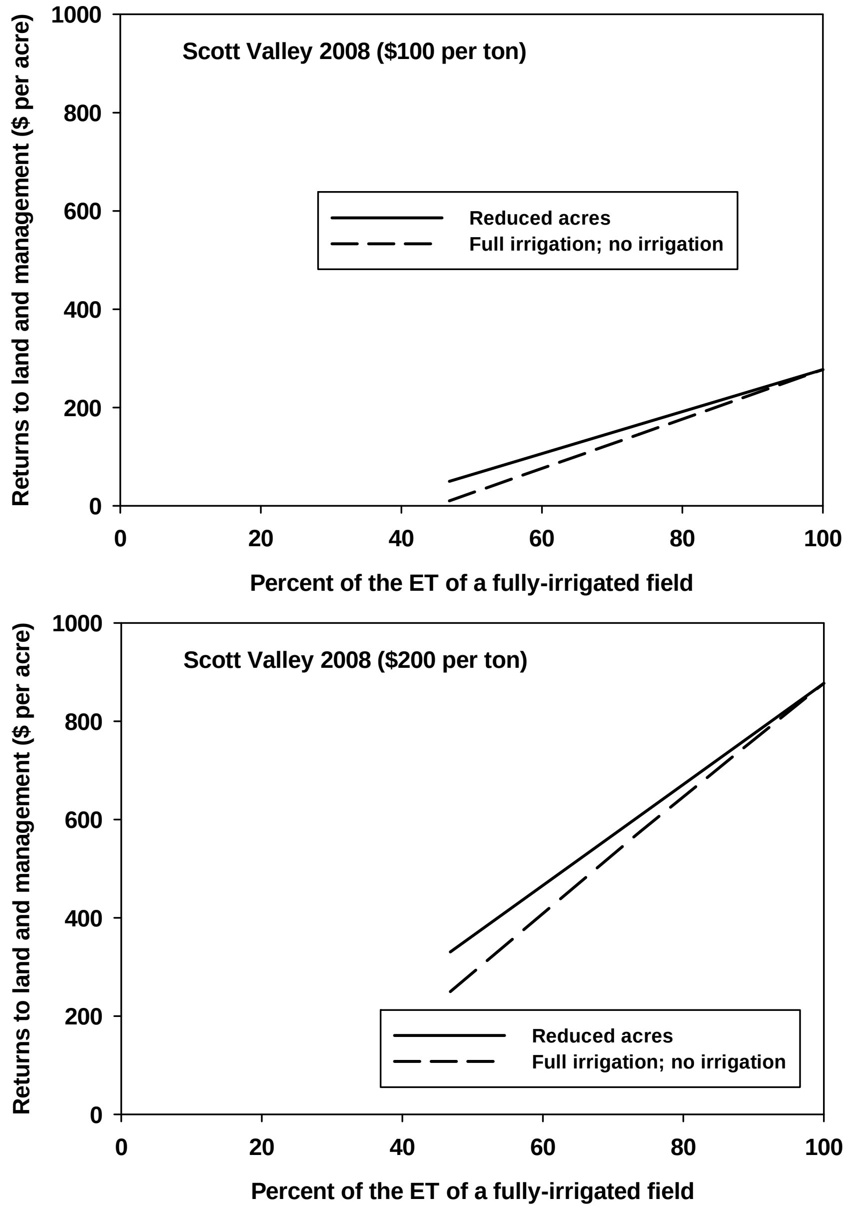


Figure 6. Effect of Strategies 1 and 2 and crop price on the returns to land and management for the Scott Valley 2008 site. Only three harvests occurred at this site.

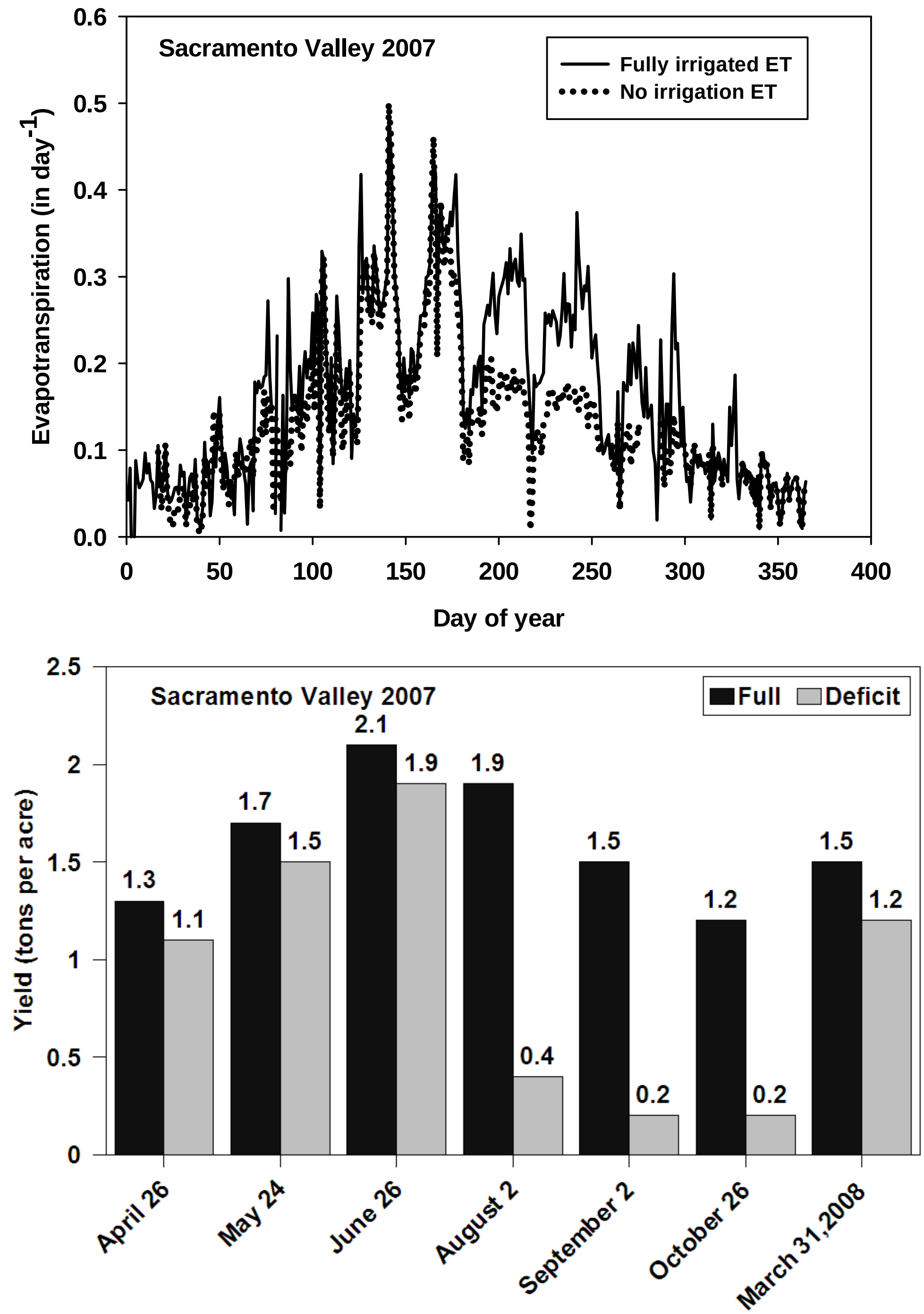


Figure 7. Effect of Strategy 2 on evapotranspiration and yield for the Sacramento Valley 2007 site. Full irrigations occurred for the first part of the crop season; no irrigations occurred after mid-June.

INTERGOVERNMENTAL AGREEMENTS: TAKING ADVANTAGE OF IRRIGATION DISTRICT PARTNERSHIPS

Cortney D. Duke[1]

ABSTRACT

In the current climate of increased regulation and limited resources many irrigation districts are looking for ways to save costs and increase efficiency. One way to maximize resources and keep service costs low is to find partners to provide services. Some districts are looking to form new partnerships to allow sharing costs, facilities, infrastructure and personnel. Other districts are looking to more clearly define responsibilities and liabilities with partners to streamline their services and protect their interests. As districts review their options, they must consider their goals and expectations for joint management.

Prior to entering into any type of partnership, an irrigation district must examine the variety of partnerships available to it and consider which type of partnership will best serve its needs based on the district goals and purposes. The irrigation district must also determine whether it has the necessary authority to form the desired partnership. This paper first investigates the range of partnering options available to irrigation districts, from forming sub-districts to establishing intergovernmental agreements ("IGAs"). The paper also focuses on the partnership created by an intergovernmental agreement, explores the authority for such agreements, and examines key components of intergovernmental agreements. Whether driven by necessity or simply in the pursuit of efficiency, this paper explains the benefits realized by an irrigation district forming an intergovernmental agreement as opposed to another joint management enterprise.

INTRODUCTION

When asked to name some of the most notable partnerships of all time you may think of Fred Astaire and Ginger Rogers; Stan Laurel and Oliver Hardy; Richard Rogers and Oscar Hammerstein. But what about your irrigation district and another public agency? Perhaps.

The benefits of a good partnership are universal and can transform an otherwise common task into an extraordinary and memorable innovation. While a partnership between your irrigation district and another public agency may not result in a standing ovation, the outcome of a good irrigation district partnership can increase efficiency, and result in providing new or better services and save resources and costs.

There are various ways irrigation districts may join forces to share costs, facilities, resources and management responsibilities. Districts may share the expense of routine maintenance costs of common or shared canals or pipelines. Districts also may share the

[1] Attorney, Schroeder Law Offices, P.C., PO Box 12527; Portland, OR 97212; c.duke@water-law.com.

costs associated with maintaining or improving infrastructure such as a common point of diversion or constructing required new infrastructure such as a new fish screen. Districts may join forces to share facilities such as canals and pipelines and storage buildings for equipment. Districts share not only services but personnel, such as secretaries, clerks, computer operators and financial analysts. As increased regulatory oversight grows, Districts may team up to share capital and intellectual resources to complete environmental or feasibility studies that are required to implement new programs such as aquifer recharge. In some cases, a smaller district may join forces with a larger district and request the larger district take over management of one portion or the entire smaller district. Some districts may choose to merge and form subdistricts, with the remaining district accepting the possibility of assuming debt and liability from the merging district. Other districts may consider entering contracts for shared management and operation. However, for districts wishing to retain some autonomy while sharing resources, intergovernmental agreements may provide the best solution.

Intergovernmental agreements provide districts with an opportunity to share personnel, enter into contracts for operation, and share equipment and facilities. IGAs allow districts to have broad management authority while maintaining a distinct division of responsibilities and liabilities. Thus, parties remain responsible and liable for activities undertaken prior to or not contemplated by the agreement. Additionally, the parties remain responsible for their statutory responsibilities and duties. Such an arrangement allows districts to take advantage of pooled resources without giving up the functions and daily operations of each unique district.

This paper initially explores the various types of legal partnerships that irrigation districts are allowed, followed by a focus on IGAs and examining the specifics of IGAs including (1) the statutory authority for IGAs and (2) key components of IGAs. The paper concludes with detailing the benefits of IGAs over other joint management enterprise options.

TYPES OF IRRIGATION DISTRICT PARTNERSHIPS

As a starting point to this discussion, it is important to remember that an irrigation district is a quasi-governmental entity. As such, its power to form partnerships is provided by statute or implied by the specific powers granted to the governing body. The legal authority for forming any type of partnerships and the limitations of those partnerships should be fully examined prior to forming the partnership.

Merger

An irrigation district may be merged and included within another special district, including another irrigation district. A merger of districts results in the extinguishment, termination and cessation of the existence of the district seeking merger by being united and absorbed into the surviving district.

The process for merging two irrigation districts typically involves the district to be merged ("extinguished district") presenting a petition to the governing body of the surviving district. The petition will be accepted by the governing body of the surviving irrigation district if the governing body makes a determination that the merger is in the best interests of the surviving district. If the surviving district's governing body accepts a petition for merger, the surviving district must hold an election for the purpose of allowing the patrons of the district to consider the merger question. Even if an election on the question of merger is not statutorily required, it is prudent for the surviving district to provide an election for public participation.

If the result of the election is a majority vote in favor of the merger, the indebtedness of each district is determined and entered upon the records of each district. The division of indebtedness shall be ordered and be binding on both districts. A debt distribution plan should be developed which provides for the distribution of indebtedness and may require that the extinguished district remain solely liable for all or any portion of any indebtedness outstanding at the time of the merger. This way, any existing debt of the extinguished district remains the sole responsibility of the original patrons (customers) of the merged district.

After the division of indebtedness is ordered, the districts shall be one district and the lands of the extinguished district shall be included in the surviving district. The patrons of the extinguished district shall have the same privileges and obligations in all respects as if originally included at formation of the surviving district.

Inclusion of lands and formation of a sub-district

The governing body of an irrigation district may accept a petition from the landowners of another district for inclusion in the district. Once the lands are included by the inclusion process, the district may form a sub-district for the newly included lands. A sub-district may be formed upon a petition to the board of directors from the landowners wishing to create a sub-district or by resolution of the governing body of the district. Once formed, the sub-district may be operated and maintained as a separate district within the larger district.

Creating sub-districts stands out as a practical way for the district to manage unique portions of the district individually and separately from the rest of the district. Creation of a sub-district also may allow a district to assume management and operation of existing infrastructure and include an existing district in its boundaries without affecting the existing members in the district's current boundaries. The governing body may assess the landowners in the sub-district additional charges as necessary to facilitate the original district's administration of the sub-district's delivery and maintenance needs.

The lands and owners within a sub-district are liable for any claims, damages, costs, expenses, debts or other liabilities of or against the district that arise out of or are incurred in the operation and maintenance or improvement of the works of the sub-district. Forming a sub-district for those lands allows the Board to manage the sub-district lands individually as well as limit the potential liability associated with debt and project facilities.

<u>Contract for operation and maintenance</u>

An irrigation district in most jurisdictions may generally make and execute all necessary contracts in carrying out the irrigation district law. Accordingly, an irrigation district may enter into a contract with another party, including another irrigation district, for the purpose of operating and maintaining water delivery infrastructure or for any other management activities authorized by the law. The contract would describe the specific acts, responsibilities, obligations and liabilities of each district party to the contract.

The benefit of contracting for operation and maintenance or delivery of services is that the power is broad and the district is able to contract for nearly any purpose that is consistent with the authorizing law. However, contracting also has negative aspects and limitations. Among the negative aspects of contracting by districts is the cost associated with negotiating, drafting, and enforcing the contracts. In addition, because a contract is controlled and interpreted only by its four corners (or what is written in the contract itself) even the most thoroughly drafted contract may overlook important details or neglect to include essential terms. A contract does not provide the same flexibility or fluidity to a district that operating under statutory authority does.

<u>Intergovernmental Agreement</u>

An intergovernmental agreement is a voluntary written agreement between two or more units of local government. An IGA while like a contract, offers government broader management authority and power to the parties. IGAs also provide greater protection against potential liability because an IGA automatically secures very distinct division of responsibilities and liabilities between the parties by recognizing the underlying entities' statutory authorities and duties.

The authority, key components, benefits and operation under IGAs are discussed in the following section.

INTERGOVERNMENTAL AGREEMENTS

An IGA is a voluntary contract between local governments which authorizes the contracting entities to either (1) jointly perform a certain act or provide a certain service or to (2) form a third entity, separate from the original district to perform a certain act or provide a certain service. IGAs may take several different technical forms including:

- <u>Intergovernmental Service Contract</u> in which two governmental units agree that one unit will provide delivery of a service in exchange for a fee from the other unit;
- <u>Joint Service Agreement</u> in which two or more governments agree to jointly plan, and deliver services; and

- Intergovernmental Service Transfer in which the responsibility for providing a service is permanently transferred from one governmental unit to another.

For purposes of this paper an IGA is assumed to be a joint service contract. In general an IGA allows two or more authorized entities, which are generally defined by statute as "local units of government" or "public agencies" to establish an agreement which describes how the two governments will cooperatively act to accomplish a certain purpose or purposes. An IGA describes relationships between the governments, defines the authority of the contracting parties and details obligations designed to achieve greater efficiency though mutual cooperation. IGAs may allow for sharing of staff, infrastructure and resources in this process. IGAs share common elements, although they may vary from state to state. IGAs are authorized by statutory authority, should be comprised of common key components, and result in universally recognized benefits.

Authority

State constitutional and statutory provisions provide the legal framework for establishing IGAs. Most states have passed laws which broadly authorize the establishment of some form of intergovernmental cooperation agreements. Some states provide general authorization for IGAs while others provide separate statutory authority for forming specific types of IGAs for particular purposes, such as formation of an IGA for developing public housing or an IGA for joint land use planning. The general authorizing statutes for establishment of IGAs in Oregon, Nevada, Utah and Colorado are discussed below.

In Oregon, IGAs are provided for in Oregon Revised Statutes Chapter 190. An intergovernmental agreement is defined as a written agreement between two or more units of local government for the performance of any or all functions and activities that any of the parties to the agreement is empowered to perform pursuant to its authorizing statute. ORS 190.010 and ORS 190.030. An irrigation district is considered "a unit of local government established to deliver water" pursuant to ORS 190.125(4).

In Nevada, IGAs are provided for in Nevada Revised Statutes Chapter 277. NRS 277.090 provides that an IGA may be established "…to permit local governments to make the most efficient use of their powers by enabling them to cooperate with other local governments on a basis of mutual advantage and thereby to provide services and facilities in a manner and pursuant to forms of governmental organization which will best accord with geographic, economic, population and other factors influencing the needs and development of local communities." Irrigation districts are subject to the Chapter 277 authorization pursuant to NRS 277.100(1). The parties to an IGA in Nevada may jointly exercise any power or authority capable of being exercised by either party to the agreement.

Utah allows "…local governmental units to make the most efficient use of their powers by enabling them to cooperate with other localities on a basis of mutual advantage and thereby to provide services and facilities in a manner and under forms of governmental organizations that will accord the best with geographic, economic, population and other factors including the needs and development of local communities…" by establishing IGAs. Utah Code, Chapter 11-13-102. Special districts, including irrigation districts, are authorized to enter into IGAs pursuant to Code Section 11-13-103(13)(a). The parties to an IGA created in Utah are authorized to provide or exchange services that either government unit is authorized to provide. Code Section 11-13-202(1)(b) and (c).

Colorado authorizes IGAs pursuant to Colorado Revised Statutes Title 29-1-203. "Governments may cooperate or contract with one another to provide any function, service, or facility lawfully authorized to each of the cooperating or contracting units, including the sharing of costs, the imposition of taxes or the incurring of debt, only if such cooperation or contracts are authorized by each party thereto with the approval of its legislative body or other authority having the power to so approve." Colorado specially provides that special districts which own or operate water systems or facilities may establish IGAs. C.R.S. 29-1-204.2. The powers of an entity established under a IGA for development of water resources under this section is empowered with specific statutory powers as authorized in C.R.S. 29-1-204.2(3).

Key Components

Statutory provisions for establishing IGAs differ from state to state. Nearly all statutory authorizations for IGAs provide certain procedural requirements that must be met before a local governmental may enter an IGA. The scope and severity of these requirements vary from state to state and necessarily affect the kind and form of IGAs created. For example formation of certain IGAs in Nevada requires approval by the Attorney General or other officials before the agreement is effective. If the purpose of the IGA will require the expenditure of more than $25,000 the agreement must be submitted to and approved by the Nevada State Attorney General.

Likewise, some statutes authorizing IGAs require that the IGA generally or specifically contain certain terms. For example, in Utah an IGA for joint or cooperative action must specify: (1) duration; (2) the agreement's purpose(s); (3) the manner of financing; and (4) the permissible method or methods to be employed in accomplishing the partial or complete termination. Utah Code Section 11-13-206. Other states generally provide that the IGA may be established for lawful purposes, limited only by the contracting parties' inherit powers.

Where the authorization for creation of an IGA is specific, additional requirements may apply, including requirements regarding the management of the entity created by the IGA. In both Colorado and Oregon, the establishment of IGAs for purposes of development of water resources requires the appointment of a separate board of control in the IGA.

Pursuant to C.R.S. 29-1-204.2 an IGA for the development of water resources, systems or facilities or drainage facilities must establish and organize a governing body of the entity. The IGA must establish the number of directors, their manner of appointment, their terms of office, their compensation, the procedures for filling vacancies on the board and the duties of the board.

Likewise the Oregon statute, ORS 190, specifically anticipates that organizations established to deliver water, including irrigation districts, may enter into such agreements to deliver water under a "joint board of control." ORS 190.125. The joint board of control is specifically required to be comprised of the district managers of the parties to the agreement. The joint board of control created by an IGA may undertake cooperative activities, such as (1) sharing personnel; (2) entering into contracts for operation; (3) sharing use of equipment and facilities; and (4) other authorized cooperative activities.

Any entity considering an IGA should conduct a thorough review of the statutory, the procedural and content requirements before execution of an IGA. In lieu of or in addition to the statutory requirements, several key components are common and should be considered and incorporated into an IGA. The components are detailed below and provided in the sample IGA at the conclusion of this paper.

1. Purposes: The purpose or purposes for which the IGA is entered into should be clearly stated and defined. The purpose may be broad or specific but must have a basis in the statutory power of one, both or all the contracting parties depending on the jurisdiction.

2. Authority: The statutory or constitutional authority for entering into the IGA should be clearly stated. If one or more of the purposes of the IGA is based on an implied power of one of the local governments, the justification for the IGA should be adequately explained.

3. Implementation of Obligations and Administrative Responsibilities: The who, how, what and when's of the IGA should be provided in detail. The IGA should clearly provide for what action is to be done and by what means. The IGA should detail if a separate governing body will oversee the purposes of the IGA. The IGA should provide who will complete each action and who shall keep records and reports of the functions completed under the IGA. The greater detail provided in this regard will eliminate unnecessary confusion in implementation of the IGA purposes.

4. Terms for Enforcement: The IGA should incorporate provisions related to enforcement of the agreement and provide for damages for failure to cooperate. The IGA may be enforceable though mediation and arbitration or a civil action.

5. Duration and Review Methods: The IGA should be effective for a specific time. The IGA may terminate automatically upon the accomplishment of a certain task or series of tasks or may end on a date certain. Alternatively the IGA may be effective for an indefinite period of time and proposed to be perpetual. Regardless of the duration intended, all IGAs should provide that

the terms of the IGA will be reviewed periodically. Providing for periodic review of the IGA and the implementation of the IGA will help ensure the IGA accomplishes the primary goal of increasing efficiency and saving resources. The IGA should also provide a time for evaluating the effectiveness of the IGA and a method for amending or updating the terms and conditions of the IGA if required.

Benefits of IGAs

Among the primary benefits of an IGA are the focused cooperation, coordination and common goal planning. The cooperative spirit of an IGA is intended to result in reduced delivery costs; effective services; use of shared capital, infrastructure and expertise; and efficient management of limited resources. Due to the varied purposes for which an IGA may be formed, an IGA can be tailored to meet the unique needs and goals of a service area. In an age of aging infrastructure and limited financial resources, an IGA allows local governments to focus budget, resources and operations in the existing service area to the highest efficiency while pursuing common goals and innovations.

IGAs are an attractive vehicle for irrigation districts looking to partner with other local governments for providing services to its patrons. The creation of an IGA can allow an existing district to take over operation and management of a ditch or series of ditches without changing the basic structure of the district. In certain cases, one irrigation district may be able to deliver water to another district without assuming the other district's assets and liabilities or diluting its member base.

For irrigation districts, an IGA has specific advantages over the other types of partnerships discussed at the beginning of this paper. First, an IGA can be established and implemented in a more expedited manner than the other types of partnerships. Creation of an IGA does not require an election or a lengthy public participation process. Second, though the terms of an IGA will require some negotiation and time to draft and execute, the administrative burden is often less than a merger or inclusion and formation of a sub-district. An IGA does not require a survey or change in the district boundaries or a change in the district assessment roles or billing process. Third, an IGA allows for a new governing body to assume responsibility for implementation of the IGA without an additional burden on the existing board members and staff. Finally, an IGA has benefits over a contract for a specific operation or management activity because an IGA automatically carries with it the entire specific and inherent duties of the local governments. There is no need to draft a lengthy contract covering each of these aspects because they are automatically assumed in the IGA. For this reason, the potential liabilities of each local government are innately less because each entity carries its responsibilities and duties with it into the contract. The chart below demonstrates these comparisons:

Table 1. Partnership Comparison Chart

	One Board Management	Requires Change in Assessment/Billing	Assumption of Liability/debts	Requires Change in District Boundaries/Management
Merger	Yes – merged Board of Directors is terminated	Yes – merged district lands may be assessed in amount different from district patrons	Surviving District does not assume existing debt and liabilities but may assume future debt and liabilities	Yes
Sub-District	Yes – Board of directors manages sub-district	Yes – sub-district lands may be assessed in amount different from district patron	No	Yes
Contract	No – two Boards remain	Depends on Contract Terms	As provided by Contract	No
IGA	Joint Board of Control created and each board retains independent powers	No	No	No

Examples of Applications of IGAs with Irrigation Districts

City of Bend and Central Oregon Irrigation District

The City of Bend and Central Oregon Irrigation District ("COID") entered an IGA which committed the City of Bend to pay COID approximately $280,000 to cover the costs associated with a piping project through City property. Specifically, COID operated a canal that ran through City property as it delivered irrigation water to downstream patrons in four counties. The COID canal ran along a right-of-way granted to COID under state and federal law. COID initiated a project to pipe the canal as part of a conservation project. Pursuant to COID's authorization, improvements within the right-of-way were controlled solely by COID. Work outside the authorized right-of-way would require agreement with the City.

The engineering plans submitted to the City by COID revealed that the water volumes in the canal required a covered pipe elevation that would be approximately 12 feet above the natural grade of the surrounding land. Upon review of COID's plans, the City felt the 12-foot berm that would be created would interfere with the City's future street and utility connections for the property. The City further determined that the berm would interfere with future commercial and residential development. The City requested that COID excavate the canal in order that the pipeline constructed would lay lower in the ground.

After negotiation and execution of an IGA, the District agreed to lower the level of the pipeline and allow the City access along and over the pipeline to support future development. The City likewise agreed to grant the District additional access as well as provide funds for the extra cost to engineer and construct the pipeline at a lower elevation. The IGA is set to expire in 2015, the date the construction is anticipated to be completed.

Washington County and Tualatin Valley Irrigation District

In 2008, the residents of Washington County approved the expenditure of tax funds for specific roadway improvements. The roadway improvements would impact several irrigation waterlines owned by the United States Department of the Interior, Bureau of Reclamation and which were operated and maintained by the Tualatin Valley Irrigation District ("TVID") under a repayment contract. As part of the roadway improvements, the County desired to relocate a portion of the impacted waterlines to new locations in existing or to be acquired right-of-ways.

After negotiation and execution of the IGA, the County agreed to pay TVID for the cost incurred by TVID relocate and reconstruct the waterlines that would be required to be moved. TVID agreed to take primary responsibility for ensuring the impacted waterlines were relocated and protected including completing engineering plans and overseeing construction. The County further agreed to bear the cost of obtaining any new right-of-ways required to effectuate the relocation.

As part of the IGA, both the County and TVID appointed a liaison to coordinate and oversee management of the IGA. The IGA was to expire after three years and provide a term that allowed for amendment of the terms of the IGA every year as needed.

CONCLUSIONS

The pressure of limited budgets, dwindling resources and pressure to be cost effective are sure to grow in the next decade. Districts that wish to continue to provide quality services to patrons while conserving resources will have to look for partners to meet the needs of the future. While an irrigation district has a variety of options open to it for forming partnerships, intergovernmental agreements stand out as a practical choice for partnering. Because intergovernmental agreements allow an irrigation district to partner with another local government which is already organized for specific purposes, the two governments can work together cooperatively to provide patrons and members the most efficient and cost effective service.

INTERGOVERNMENTAL AGREEMENT

Between
Irrigation District* and *Other Special District or Public Agency

for

Describe purpose of entering agreement

1. THIS AGREEMENT is for the purpose of defining the individual obligations of *Irrigation District*, and *Other Special District or Public Agency* related *describe purpose(s) for entering agreement*

2. *Describe other background recitals*

NOW THEREFORE, THE PARTIES AGREE AS FOLLOWS:

***IRRIGATION DISTRICT* OBLIGATIONS**

1. *Irrigation District* will *list and describe any and all obligations and duties specific to the irrigation district in carrying out the purpose of the agreement.*

2. ____

3. ____

***OTHER PUBLIC AGENCY* OBLIGATIONS**

1. *Public Agency* shall *list and describe any and all obligations and duties specific to the other public agency in carrying out the purposes of the agreement.*

2. ____

3. ____

GENERAL OBLIGATIONS

1. *Irrigation District* and *Other Public Agency* will cooperate regarding *list and describe joint obligations.*

2. *Irrigation District* and *Other Public Agency* will assist in coordination of any work or issues of mutual concern such as ___________________________, if needed.

3. TIME LINE: *Irrigation District* and *Other Public Agency* will endeavor to complete the tasks described in this agreement by _____________________, 20__.

4. TERMINATION: This agreement will remain in effect until amended or terminated by mutual consent or by termination upon thirty (30) days written notice from one party to the other parties.

5. Nothing herein shall be construed as obligating any of the parties to expend or involve the other parties in any contract or other obligation for the future payment of money.

6. This agreement is neither a fiscal nor funds obligation document. Any endeavor involving reimbursement or contribution of funds by and between the parties arising under this agreement shall be in accordance with applicable laws, regulations, and procedures. Such endeavors shall be provided by separate written agreements by authorized representatives of the parties.

JOINT BOARD OF CONTROL

1. The general obligations of this agreement, as described in this agreement, shall be overseen by a Joint Board of Control.

2. The Joint Board of Control shall be comprised of: *list members of joint board of control*

3. The terms of the joint board of control shall be __________________________.

4. *List and describe any other issues related to the Joint Board of Control – i.e. compensation, meeting times, etc.*

INDEMNIFICATION

1. Each party shall be solely liable for third party claims arising from the actions of that party's officers, employees and agents.

2. Each party shall be solely liable for its employees Workers' Compensation claims, regardless of which party is exercising supervision and control of the

project when the claim arises.

3. When the parties share supervision and control over a project, each party shall be liable for third party claims arising for the actions of its officers, employees and agents.

4. Each party acknowledges responsibility for liabilities arising out of the performance of this agreement and shall defend, hold harmless and indemnify the other party, its officers, agents, and employees for any and all liability, settlements, loss, costs, and expenses in connection with any action, suit or claim resulting or allegedly resulting from negligent performance of this agreement.

IN WITNESS WHEREOF, the undersigned parties have agreed to the terms and provisions stated in this Agreement.

APPROVED AS TO FORM	APPROVED BY:
Legal Counsel Date	Chief Administrative Officer Date
Contracts Compliance Analyst Date	
Recommended by:	
Public Works Director Date	

APPROVED AS TO LEGAL SUFFICIENCY	Chair, Board of Directors Date
District Attorney Date	
APPROVAL RECOMMENDED	

COST EFFECTIVE IRRIGATION MODERNIZATION: NEPAL'S EXPERIENCES

Suman Sijapati[1]

ABSTRACT

With rising cropping intensity and more and more adaptation of high yielding varieties, the level of irrigation service demanded by farmers is on the rise. This coupled with greater fluctuations in supply sources due to issues like climate change has been making the task of the irrigation water supply providers even more difficult. In order to meet this rising demand of service level, it is essential to have appropriate infrastructure and matching technology which needs to be established in the case of new schemes and continuously maintained and upgraded in the case of existing irrigation schemes. While new technologies are being developed to meet these requirements the other key challenge lies in making it efficient and cost effective.

This paper gives an overview of the context of Nepal and explains the need of making investments in irrigation more cost-effective. It mentions about the exercises that were carried out in large irrigation schemes using the approach and tool developed by the Food and Agriculture Organization on the United Nations (FAO) and discusses how the country was able to identify the needs and plan and implement the irrigation modernization works in a cost-effective way and produce optimum results using the limited available resources.

INTRODUCTION

Nepal is a landlocked South Asian country located between India and China with a total area of 141,181 sq. km. Its resource base for agriculture is severely limited by topographical constraints. The terrain consists of 'Terai' (plain land) in the south, central hilly region and rugged Himalayas in the north with elevations extremes from 70m to 8,850m. Total arable land is about 2.64 million ha (16% of the country) with permanent crops on less than 1% (see Figure 1).

[1] Senior Divisional Engineer, Department of Irrigation, Government of Nepal, Address: 3/237 Dhobighat, Lalitpur, Nepal. Phone #: +977 1 5532800; +977 9841388100 (cell). Email: suman@sijapati.wlink.com.np

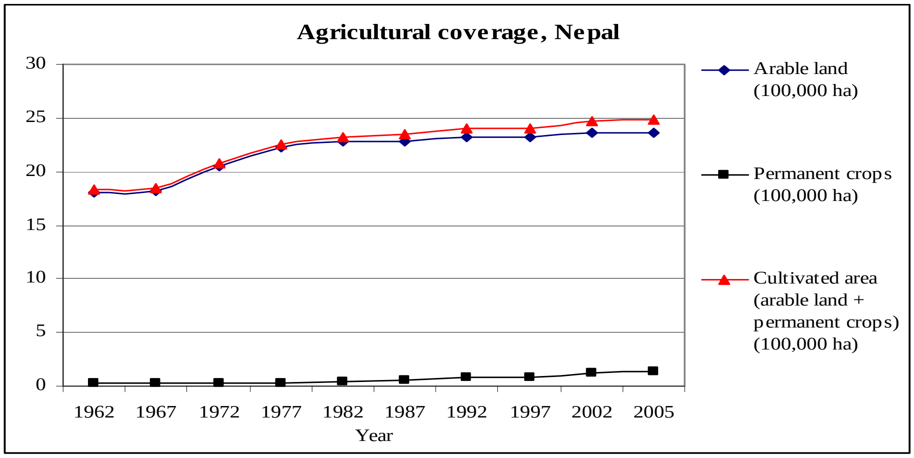


Figure 1. Agricultural Coverage and its Trend, Nepal (Source: FAO Database, 2009)

The country's population is approximately 28 million of which one-third lives below the poverty line. Agriculture provides livelihood for three-fourths of the population and accounts for about 33% of gross domestic product (GDP). Figure 2 shows the trend of increasing population and dependency on agriculture.

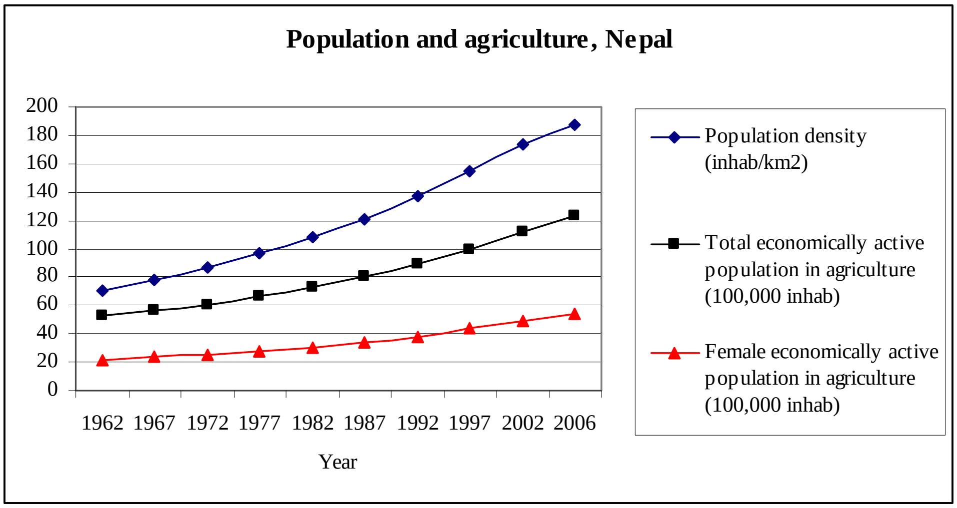


Figure 2. Population and Agriculture, Nepal (Source: FAO Database, 2009)

Agricultural practice is highly dependent on rainfall due to inadequate irrigation infrastructure or facilities. This dependency on rainfall, awaiting monsoon, significantly influences the sowing and harvesting time. Irrigated land makes about 1,170,000 ha and total annual renewable water resource is about 210 cubic km. The majority (96%) of the total fresh water withdrawal (10.18 cu km/yr; 375 cu m/capita) goes to the agriculture sector.

The Government of Nepal, with and without the support of international donors, has made continuous efforts for the development of the irrigation sector of the country over the last five decades. Despite large investments in the sector, only 51% of arable land presently has irrigation facilities while the rest remains rainfed. Furthermore, only 40% of the area having irrigation facilities gets year round irrigation while the remaining 60% receives only seasonal irrigation.

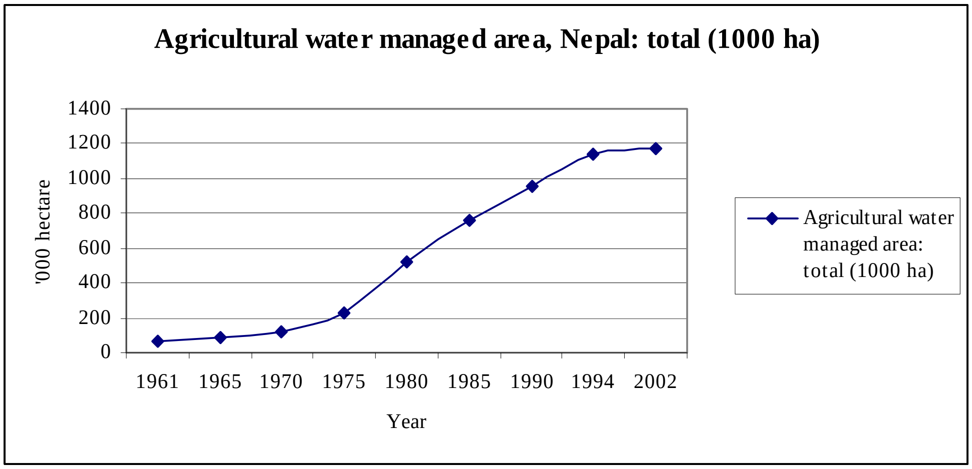


Figure 3. Agricultural Water Managed area, Nepal (Source: FAO Database, 2009)

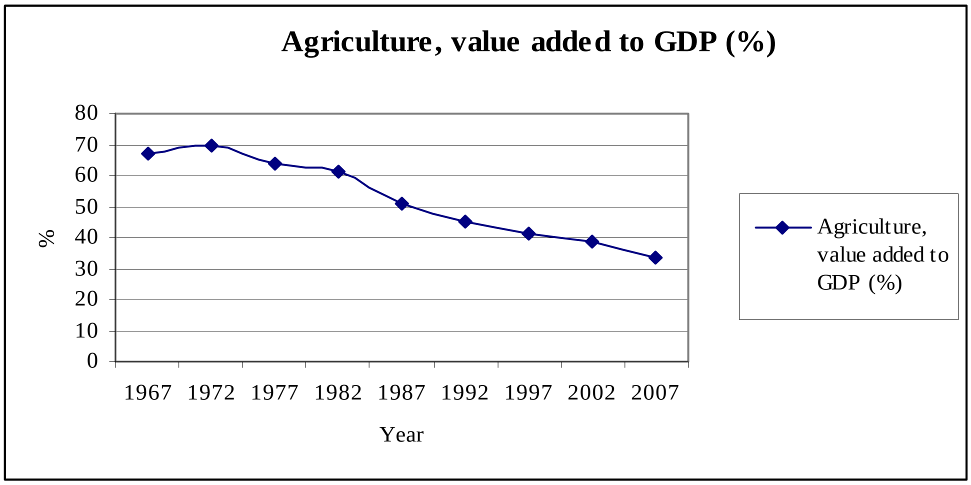


Figure 4. Agriculture, Value Added to GDP, Nepal (Source: FAO Database, 2009)

To sum up, it is evident from the above statistics that pressure on land resources (cropping intensity) is on the rise. Nepal has made notable gains in the extent of water managed area during the period from 1965 to 1995 owing to large investments made in the irrigation sector, but the relative contribution to the agriculture sector proved to be otherwise due to its continually declining share in the total economy as is evident from Figure 4 above. Hence, the country presently faces a stiff challenge of making the agriculture /irrigation sector more efficient.

HISTORICAL PREVIEW OF IRRIGATION DEVELOPMENT IN NEPAL

Nepal has a strong history of traditional canal systems that were built by farmers since time immemorial and are still serving almost half the total irrigated area in the country. These systems were conceived and constructed mainly for supplemental irrigation by the local farmers themselves, based on their local knowledge, experience, and values. It was done by mobilizing necessary resources at community level, without any technical input and financial support from the state or external donors.

Typically, they are run-of-the river gravity irrigation systems diverting water from a creek using some temporary brush-wood type diversions which get washed away with each flood and/or requires frequent maintenance. They were constructed of local materials such as wood, clay, stones, etc. The size of command areas varies from less than a hectare to a few thousand hectares. Water regulating structures, generally fewer than in modern irrigation systems, mostly have on and off type wooden planks. Operations are primarily based on proportional distribution system with very limited flow regulations, but closely follow the principles of equity, which fostered the collective and self-sustaining enterprise of collective management.

These systems divert much more water than the crop water requirements to make up for the extensive leakage and seepage along the water distribution secondary and tertiary canal networks and poor drainage structures. Local drains frequently interfere with canal water flows. On-farm water management structures are virtually non-existent and flood and furrow irrigation are common methods of water application at the farm level.

Local and collective resource mobilization practices by the local farmers through self-governed water users associations in the form of labor and kind have been crucial and exemplary for long sustained operation and maintenance of such irrigation systems both in the hills and Terai (Pradhan, 1989; Prasad et al, 1998). Performance of such irrigation systems in terms of their agricultural productivity levels have often been reported to be superior to the same in the irrigation systems constructed and managed by the government (agency) (ibid). The over acquisition and distribution of water, initially considered as a waste, has later been observed by irrigation experts to be often re-used by the downstream farmers and other water users.

In the 17th century, the state started extending support to irrigation development and the construction of a few irrigation facilities was financed and carried out by the state, e.g. Raj Kulos (King's Canals). The first major effort of the government towards irrigation development was made in 1920 with an agreement between Nepal and (the then British) India over the sharing of Sharda (Mahakali) River water for irrigation and power. The first modern canal irrigation system in the country the Chandra Canal in the eastern Terai with command area of 10,000 hectares, was constructed during 1922-28 with the assistance of Indian engineers. During 1928-51, a few more canal irrigation systems were constructed by the then Public Works Department (PWD): Jagadishpur in 1942 (1,000 ha) (renamed as Banganga in 1978 after expansion) and Juddha Canal in 1946 (2,000 ha) (renamed as Manushmara in 1976 after extension).

Later, after the formation of the then Canal Division in 1951 (now, the Department of Irrigation -DoI) the government of Nepal embarked upon full-fledged planned development of irrigation, specifically from 1957. DoI still remains, the principal government institution responsible for the planning, development and management of irrigation schemes in the country (DoI, 2008). International agreements with India on the use of the Koshi River water in April 1954 and on the Gandak (Narayani) River water in December 1959, initiated the construction of large-scale irrigation systems in the Terai. However, until the early 1960s, the country lacked adequate technical manpower and financial resources to implement large scale irrigation works and only a few medium-sized irrigation systems were constructed during the first five-year development plan period (1957-62).

Minor Irrigation Program was introduced in the second three-year development plan (1962-65) to provide low-cost irrigation facilities to farmers within a short period of time. The program included the construction of small wells, tanks, pumps and other low-cost and short duration irrigation implements. Although it was planned to provide irrigation facilities to 4,455 hectares by the end of the Plan period, the actual achievement was insignificant. The Third Plan Period (1966-70) also saw a countrywide implementation of the Minor Irrigation Program with the emphasis on participation of the beneficiaries, but the program was not very successful because of lack of awareness among the beneficiaries.

From the early 1970s, the government became more active in the construction and management of new irrigation schemes. Investment in large irrigation development in the Terai increased tremendously. This was mainly due to the increase of international capital in the form of loans and grants for the country's overall economic development. This is also reflected by the surge in irrigation development targets in the subsequent five-year development plans- from the Fourth Plan (1970-75) onwards.

Until the middle of the 1980s, irrigation development by the government remained focused on the construction of physical infrastructure and very little attention was given to the management of the completed systems. Farmers and other beneficiaries were generally at the receiving end with a passive role. Improved irrigation service to the farmers, who still were expected to pay for the irrigation water to the state, did not receive any attention. The service fee assessments were based on the gross area covered with no reference to service delivery criteria and conditions. Consequently, service fee collections remained at a meager level; hardly enough to cover even the regular operation and maintenance costs (Prasad et al, 1998). Justifying agriculture as a priority and populist sector, the technocrats of state agencies gave continuity to this unaccountability by continuing allocation of operation and maintenance funds from the state's coffer with no connection to the level of service or associated fee collections.

Improved management of government-operated irrigation systems caught attention from 1985 onwards (www.doi.gov.np). This is reflected in the implementation a command area development project in the mid 1980s and a number of other management-oriented projects during the period 1985-89: the USAID-funded Irrigation Management Project (IMP) in 1985, the Irrigation Line of Credit (ILC) in 1988 financed by the World Bank, the Irrigation Sector Project (ISP) in 1988 financed by the Asian Development Bank (ADB), and the Irrigation Sector Support Project (ISSP) in 1989 under the co-financing of the UNDP, the World Bank and ADB.

Most management oriented projects were pushed by the external donors during 1985-1989. This was immediately followed by the promulgation of relevant acts and regulations that reinforced greater collaboration with irrigators in all phases of irrigation projects. The strategy of increasing farmer participation was mainly based on the recognition that government resources alone were inadequate to meet the country's irrigation development objectives and sustain the management of government-built irrigation systems after their completion. The government aimed to expedite the pace of irrigation development and devolve maximum responsibility in the operation and maintenance of completed irrigation systems over to the farmers.

Participatory approaches and management transfer reforms were promoted and implemented as part of the solution for cost-effective and sustainable irrigation services. Eleven medium to large agency managed systems have been partially or fully turned over to the water users through the Irrigation Management Transfer Project (IMTP). However, mixed results were obtained. Some of the findings have been: i) water users of large schemes currently face the challenge of resource mobilization and severe financial constraints, and ii) users are not up to the task when it comes to technical decisions of operation and maintenance and again turn to the government for assistance.

INTRODUCTION OF MASSCOTE IN NEPAL

MASSCOTE (MApping System and Services for Canal Operation Techniques) was introduced in Nepal with the idea of evaluating the performances of some of the agency-managed irrigation systems and developing appropriate plans for modernizing them. It was first carried out in Sunsari Morang Irrigation System (SMIS) in May 2003 and later in Narayani Irrigation System (NIS) in November 2003.

MASSCOTE is a methodology developed by FAO on the basis of its own experience on modernization programs in Asia between 1998 and 2008. It aggregates all the pieces into a consistent framework, complementing tools such as Rapid Appraisal Process (RAP) and Benchmarking[2], to allow a complete sequence of diagnosis of external and internal indicators of performance and practical solutions for an improved management and operation of the system.

MASSCOTE aims at organizing the project development into a stepwise revolving frame including:

- mapping system characteristics, water context and all factors influencing management
- delineating manageable sub-units
- defining strategy for service and operation for each units
- aggregating and consolidating canal operation strategy at the main system level

[2] Rapid Appraisal Process (RAP) is a tool developed by Irrigation Training and Research Center (ITRC) of California Polytechnic State University to quickly assess irrigation system performance while Benchmarking is a similar tool developed through the initiative of the World Bank.

MASSCOTE is an iterative process based on 10 successive steps. Some steps need to be re-discussed and refined several times before reaching consistency. The ten steps are as follows:

1. INITIAL ASSESSMENT	
1. Rapid Diagnosis	Initial rapid diagnosis and assessment through RAP or others. Objectives: i. to get an initial sense of what and where the problems are, how they should be prioritized, etc.; ii. to start mobilizing the energy of the actors (managers and users) for modernization; iii. to generate a baseline assessment, against which progress will have to be measured.
2. MAPPING THE SYSTEM CHARACTERISTICS	
2. System Capacity and Sensitivity Mapping	a) Assessment of the physical capacity of irrigation structures to perform their function of transport, control, measurement, etc. b) Assessment of sensitivity of irrigation structures (offtakes and regulators) and identification of singular points. c) Mapping the sensitivity.
3. Perturbation Analysis	Perturbations analysis: causes, magnitudes, frequency and options for copping with it.
4. Mapping Water Networks and Water Accounting	a) Assessment of hierarchical structure and the main features of irrigation and drainage networks, on the basis of which partition of the system into sub-systems will be made. b) Water accounting exercise considering both surface and groundwater and mapping their opportunities and constraints
3. MAPPING THE SERVICE: COST OF OPERATION AND DEMAND PER SUB-COMMAND AREAS	
5. Mapping Service Options	Mapping options for services to users: farmers, crops and other users.
6. Mapping the Cost of Operation	Mapping the cost for current operation techniques and services, disaggregating the elements entering into the cost, costing options for various levels of services with current techniques and with improved techniques.
7. Mapping the Demand for Canal Operation	a) Assessing means, opportunities and demand for canal operation. b) A spatial analysis of the entire command area, with preliminary identification of Sub-Command Areas (management, service, etc).
4. DESIGN SUB-UNITS FOR SERVICE & OPERATION	
8. Partitioning in Management Units	Division of irrigation system and the command area into SUB-UNITS [sub-systems and/or sub-command areas] which are homogeneous, and/or separate from one to the other with a singular point or a particular borderline.
9. Canal Operation Improvements	Identification of improvement options for each Management Unit for (i) Water control (ii) Water management and (iii) Canal operation (service and cost-effectiveness).
5. AGGREGATING AND CONSOLIDATING	
10. Aggregating & Consolidating Management	a) Aggregation of options at the system level, and consistency check. b) Consolidating and designing an overall cost-effective

	Information System for supporting operation and Service Oriented Management (SOM).
A Plan for Modernization and Monitoring & Evaluation	a) Modernization strategy and progressive capacity development b) Select/choose/decide/phasing the options for improvements c) Plan for monitoring and evaluation of the project inputs and outcomes.

MASSCOTE exercises were carried out in SMIP and NIS through which quantified performances in terms of water delivery service at each canal level were determined. Through field rating and analysis, major constraints of both these systems were identified.

ANALYSIS OF IRRIGATION COSTS AND SERVICES

Another important part of the MASSCOTE exercise in the two systems was the analysis of their irrigation cost and services. Analysis of cost of operation not only revealed the cost-effectiveness of current operation and identified how it is affected by changes in the different inputs (water, staff, energy, office, communication and transportation) but also provided a good basis for cost-effectiveness of the improvements.

The estimated annual O&M cost for most large projects in the Terai was more than 400 Nepalese Rupees per hectare (NRs.400/ha) (US$1 = NRs72), with operation costs as shown in Table 1 (DoI, 1996):

Table 1. Breakdown of Operation Costs for the Level of Infrastructure in SMIS, Nepal

Component:	Operation Cost (NRs./ha)	% of total Cost of Operations
Headworks	35	10
Main Canal	50	15
Secondary & Sub-secondary Canals	120	35
Tertiary Canals & Water Courses	125	40
Total	260	100

At that time, the project operation for the SMIS consumed an annual maintenance budget of NRs. 770/ha (DOI, 2001). According to the then managers, the O&M cost in the SMIS should be NRs. 1,500/ha, with NRs. 500 for operation and NRs. 1,000 for maintenance. This amount would correspond to about 3.3 percent of the gross product in the command area for 2005. According to Pradhan *et al*. (1998), it would correspond to about 10 percent of the net income per hectare provided.

Part of the differences in the figures for O&M costs can be explained by inflation and by the increase in cropping intensity from one irrigated crop per year (rice) to more than two on average (the cropping intensity is currently 215 percent). With year-round irrigation, the service is provided for a much longer period of time and the cost of O&M increases. Therefore, a figure of NRs. 1,500/year for irrigation was considered for O&M.

This figure was compared with the cost to individual farmers of pumping groundwater. The RAP estimated this cost at NRs. 2,000–3,000 per crop/season, meaning that two crops per year would cost NRs. 4,000–6,000 with this type of supply (even more expensive where the farmer has to rent the equipment). This O&M cost corresponded to the then service level, which in many regards is not able to satisfy demand in winter and spring. Responding to the users' demand with more flexible service would demand an increment in inputs and consequently result in higher annual O&M cost.

Many farmers that have poor service from a canal, or none at all, had moved to groundwater pumping wherever it is accessible at a reasonable cost. Thus, they usually pay a high cost for an adequate, reliable and flexible service. The cost of pumping varied with the context. In Terai, Nepal, farmers spend NRs. 3,000 per season for rice. The average cost of energy for pumping groundwater to cultivate sugarcane in one hectare is about NRs. 15,100 which is much higher than the canal water fee of sugarcane in the project (see Figure 5). Therefore, it seems reasonable to consider the option of upgraded service from surface supply allowing two crops at about NRs.1,800/ha/yr (the increase being mainly due to operation). This cost was expected to be acceptable to users provided that the service really improves.

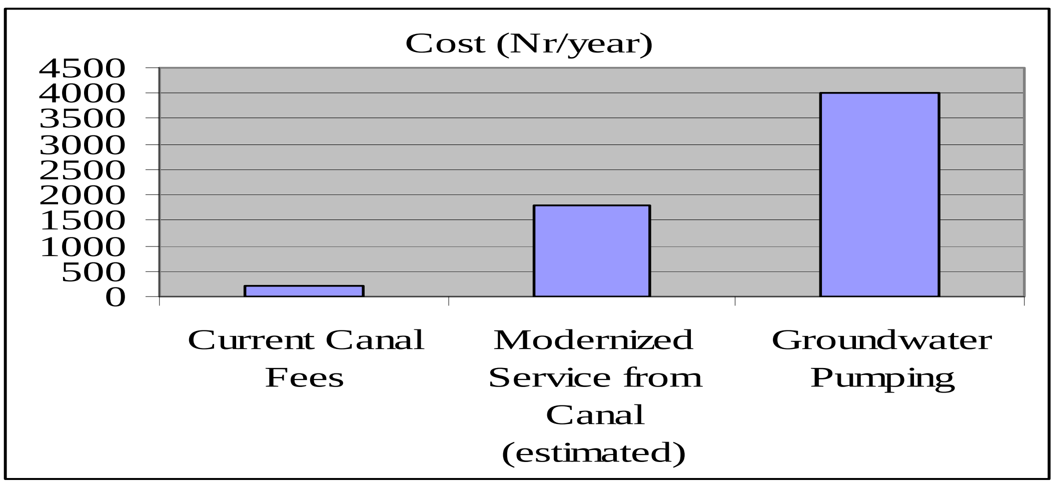


Figure 5. Comparison of Costs (Cost Analysis during MASSCOTE Exercise)

Cost analysis was also carried out for NIS. With reference to the irrigated area, the cost of operating the system is NRs. 233/ha. From the breakdown of the actual cost for different levels and items, a rough estimation of the service cost was determined for two options:

Option 1 aimed mainly at improving water management and deliveries along the main canal through tapping additional water from natural surface streams, an improved information system and better operation. This option did not target much improvement within the secondary CAs. The service (in terms of reliability and equity) to farmers would be only slightly improved. The main system level inputs would be increased significantly to face these challenges while some new allocation would be made in order to develop the local management capacity in Block 13–15. Under this option, the cost of operating the system would be about NRs. 244/ha.

Option 2 targeted Option 1 plus significant improvements in the service delivery to farmers, which basically means two crops a year and improved reliability and equity. In order to realize this option, an increase in the staff capacity at main canal level and increase in many more inputs at the secondary canal level would be required. For this option, the cost of operating the system would be about NRs 360/ha.

CONSEQUENCES AND RESULTS OF MASSCOTE EXERCISE IN NEPAL

The MASSCOTE exercises conducted in Nepal contributed both in terms of capacity building and in terms of real actions. A total of 80 irrigation related professional (27 during SMIP MASSCOTE, 24 during NIS MASSCOTTE and 29 during the summing up exercise conducted in April 2006) received exposure to the tool. The workshops were very useful in making the participants more analytical in their job assignment instead of the ‘business as usual approach’.

Its impact was also in the form of actions in the ground. Modernization plans with different options were developed through MASSCOTE exercises for both these systems. In the consequent years the operation and maintenances works in those systems were carried out very much along the lines of the recommendations of the MASSCOTE results. Due to fund constraints, even though modernization plan could not be fully executed as in SMIS, government made the funds available for NIS and option 1 recommendation of MASCOTTE was executed during 2006 and 2007. The level of service is reported to have significantly increased after the modernization works. Thus, the MASSCOTE exercise and the consequent modernization plans were very useful in providing a guideline for increasing cost-effectiveness of irrigation management in the two large irrigation systems in Nepal

REFERENCES

Department of Irrigation (DOI), 2008. Human Resources Study of DOI. In Irrigation Newsletter, number 75. Department of Irrigation. April-July 2008. Kalu, I. L., 2004. Need and Potential of Non-Conventional Irrigation Technology, APTEC, Lalitpur, Nepal.

Food and Agriculture Organization (FAO) of the UN, 2006. Modernization Strategy of Large Rice based Terai Irrigation Systems of Nepal. Rome.

Ministry of Population and Environment (MOPE), 2002. Second National Report on the Implementation of the UN Convention to Combat Desertification, Kathmandu, Nepal.

National Planning Commission (NPC), 1997. Statistical Data Profile of Participatory Database. Kaski District Development Committee. Participatory district development programme. Kathmandu, Nepal.

Pradhan, P., 1989. Patterns of Irrigation Organizations in Nepal: A Comparative Study of 21. Farmer Managed Irrigation Systems. International Irrigation Management Institute. Colombo, Sri Lanka.

Prasad, K., Thoreson, Bryan P., and David J. Molden, 2000. Tracing the History of the Development and Management of Two Irrigation Systems in the Terai of Nepal. In proceedings of the International Conference on "The Challenges Facing Irrigation and Drainage in the New Millennium", June 20-24, 2000. Fort Collins, Colorado, USA.

Prasad, Krishna C., Sijapati, S., Pradhan, P., Sharma, K. R. and Nicola Riddel, 1998. Irrigation Service Fees in Nepal. IIMI and Research and Technology development Branch/DOI, Kathmandu, Nepal.

Sijapati, S. and Krishna C. Prasad, 2005. Improving governance in Nepal's water resources sector through institutional changes. In proceedings of Third International Conference of USCID, March 29-April 2, 2005, San Diego, USA. Pp. 141-151.

Ostrom E., 1990, Governing the Commons: The Evolution of Institutions for Collective Action, Cambridge University Press.

WECS, 2003. National Water Resources Development Plan. Water and Energy Commission Secretariat, His Majesty's Government of Nepal, Singha Durbar, Kathmandu, Nepal.

WATER SUPPLY ENHANCEMENT PROJECT FOR THE POSO CREEK INTEGRATED REGIONAL WATER MANAGEMENT PLAN REGION

S. Schaefer[1]
R. Iger[2]
I. Medina[3]
P. Oshel[4]

ABSTRACT

This paper provides an overview of the Water Supply Enhancement Project (Project) for the Poso Creek Integrated Regional Water Management (IRWM) Region (Region). The Project involves implementation of both non-structural and structural measures identified in the Poso Creek IRWM Plan. A combination of local, private, state, and federal funding sources are being utilized to fund the implementation measures.

The Region is located in north Kern County and southern Tulare County of the Southern San Joaquin Valley, California, and contains predominately agricultural districts with 347,000 irrigated acres out of 500,000 gross acres. The managed water supplies for districts within the Region include:

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

Court-ordered actions and hydrologic droughts in California are causing a decrease in available surface supplies to agricultural, urban, and environmental water users. Implementation of the Project is needed to off-set existing and projected losses to surface supply reliability and to conserve groundwater. Since the Region is located at the crossroads of the California Aqueduct, Friant-Kern Canal, and the Kern River, it is an ideal location for conjunctive management.

INTRODUCTION AND BACKGROUND

The Poso Creek IRWM Plan Region (Region) is located in north Kern County and southern Tulare County of the Southern San Joaquin Valley, California as shown in Figure 1. The Water Supply Enhancement Project (Project) is being implemented based on an integrated Plan developed for the Region that provided a framework for (1) coordinating groundwater and surface water management activities through regional objectives, and (2) implementing the measures necessary to meet those objectives.

[1] Senior Engineer, GEI Consultants, Bookman-Edmonston Division, Santa Barbara, CA
[2] Principal Engineer, GEI Consultants, Bookman-Edmonston Division, Bakersfield, CA
[3] Engineer, GEI Consultants, Bookman-Edmonston Division, Bakersfield, CA
[4] District Engineer, Semitropic Water Storage District, Wasco, CA

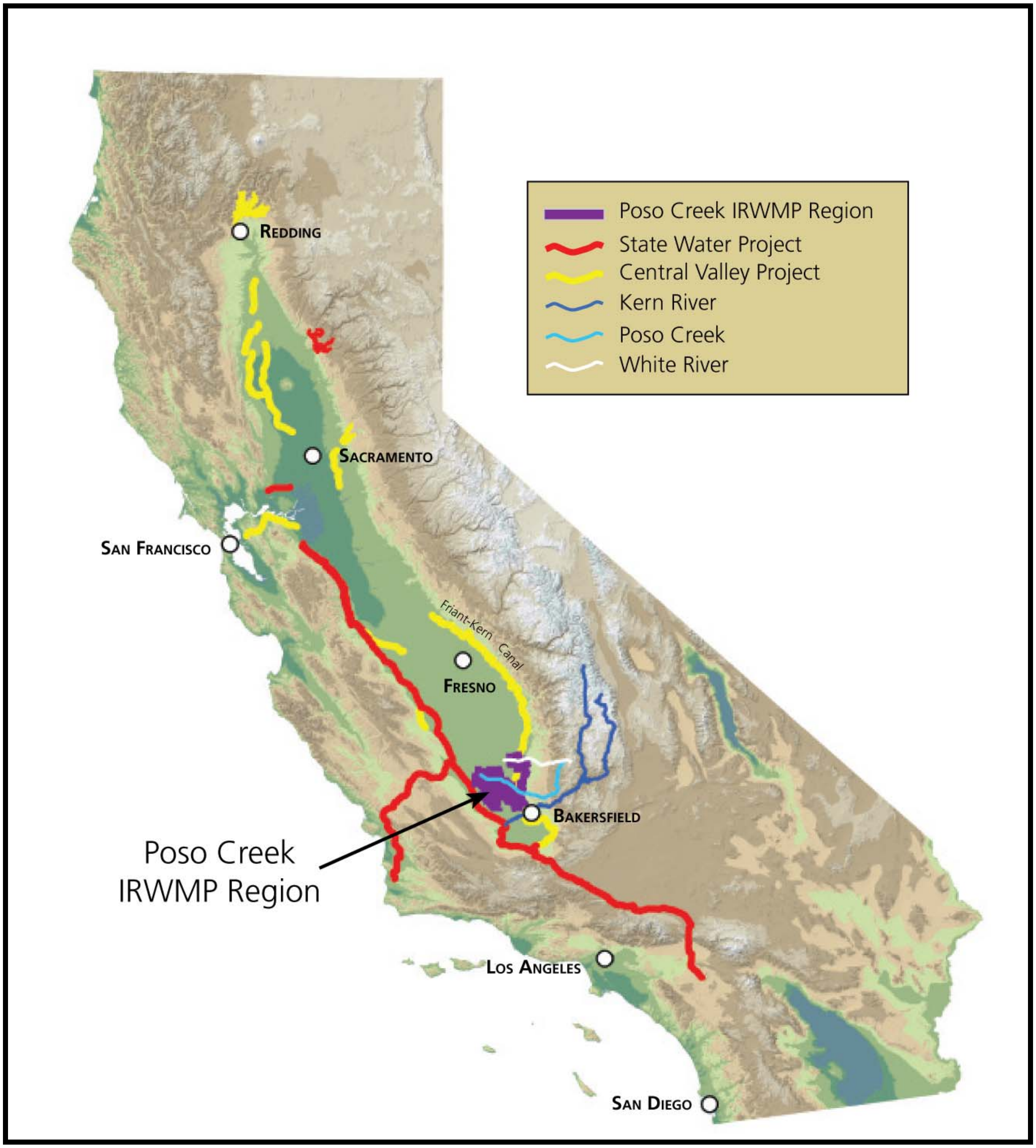


Figure 1. Location of Poso Creek IRWM Plan Region

The Plan's Regional Water Management Group (RWMG) was formed in March, 2005, and includes six special districts and one resource conservation district within the Region, as shown on Figure 2. The RWMG is an experienced group of water managers that includes:

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

The RWMG completed and adopted the Poso Creek IRWM Plan in July 2007. The RWMG, Stakeholders, and Plan Participants continue to meet monthly to coordinate implementation activities.

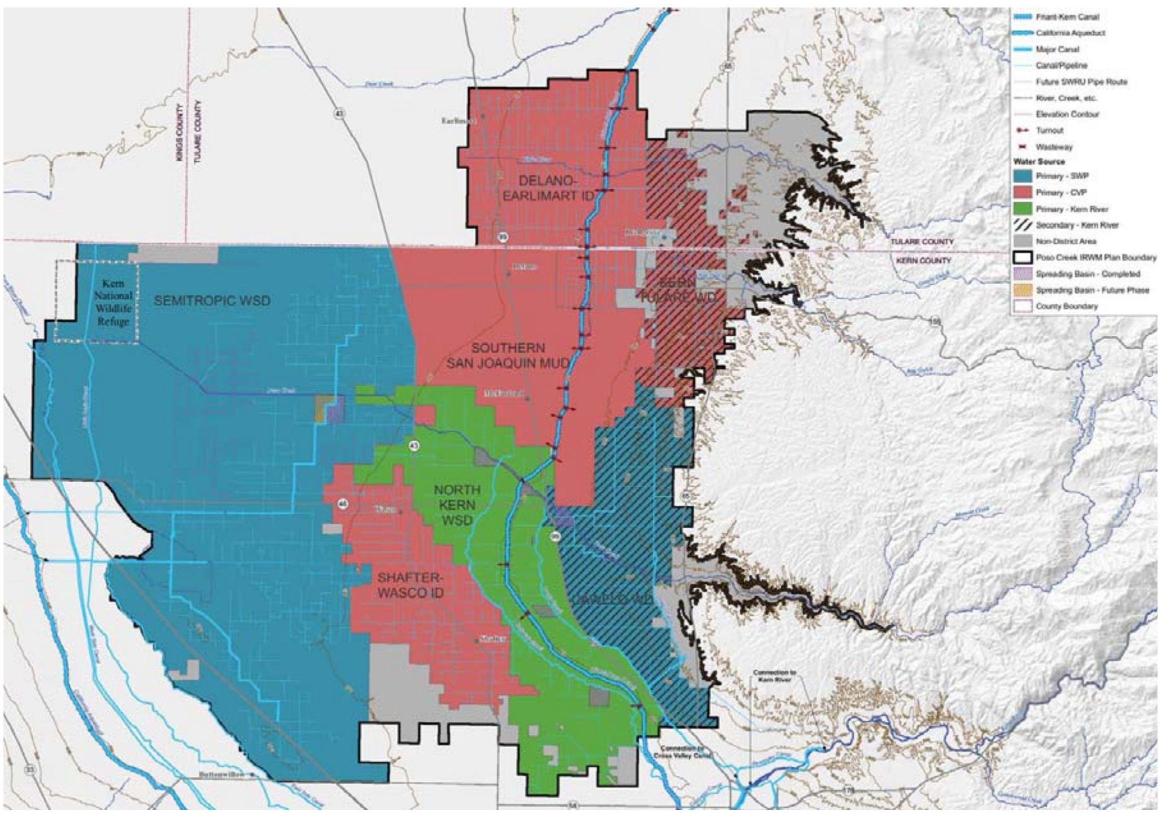


Figure 2. Districts within the Poso Creek IRWM Plan Region.

The Region has a very unique location regarding water supply and this is a valuable asset, not only to the Region but to California. The proximity of the Region to the California Aqueduct, Friant-Kern Canal, Kern River, Poso Creek, and groundwater banking facilities, combined with large conveyance and absorptive capacity, provides an ideal setting for expanded conjunctive use operations.

In addition to the unique location, the Region's assets include a groundwater basin that is common to the districts with multiple surface water supplies from several sources. Once the individual districts began meeting and considering expanding conjunctive water management operations as a regional group, it became apparent that the reliability of water supply to the Region could be increased by operating cooperative programs among the districts. Since the RWMG members share common interests and the group is of a manageable size, water management programs to off-set losses in surface water reliability and to conserve groundwater developed quickly from planning to implementation.

CONJUNCTIVE WATER USE EXPERIENCE IN REGION

The agricultural districts in the Poso Creek region have been participating in conjunctive water use for over 50 years, with some of their landowners practicing conjunctive use for over 100 years. In particular, conjunctive water use refers to the coordinated and planned use and management of both surface water and groundwater resources to maximize the availability and reliability of water supplies in a region. (DWR, 2009)

Surface water supplies can be stored through *in-lieu* recharge (delivery of surface water for irrigation instead of pumping groundwater) and direct recharge (delivery of surface water into ponds or channels) in individual districts and also in neighboring districts that form banking and exchange agreements. The projects identified in the Poso Creek IRWM Plan reflect the RWMG's primary goal to enhance regional water reliability and conserve groundwater through coordinated operation of neighboring district facilities to compliment their in-district facilities.

HISTORICAL AND PROJECTED WATER SUPPLY FOR THE REGION

The Region is underlain by the Poso Creek Hydrologic Unit, a subbasin of the Tulare Lake Basin (DWR No. 5-22.14) (Poso Creek RWMG, 2007), thus all of the districts have usable groundwater. The various water supplies for the Region are summarized in Table 1, followed by the proportions of the local and imported surface water supplies.

Table 1. Water Supply Sources for the Regional Water Management Group

	SWP	CVP Delta	CVP Friant	Kern River	Poso Creek or Other Local Streams	Ground-water
Cawelo	✓			✓	✓	✓
Delano-Earlimart			✓		✓	✓
Kern-Tulare		✓		✓	✓	✓
North Kern				✓	✓	✓
Semitropic	✓				✓	✓
Shafter-Wasco			✓			✓

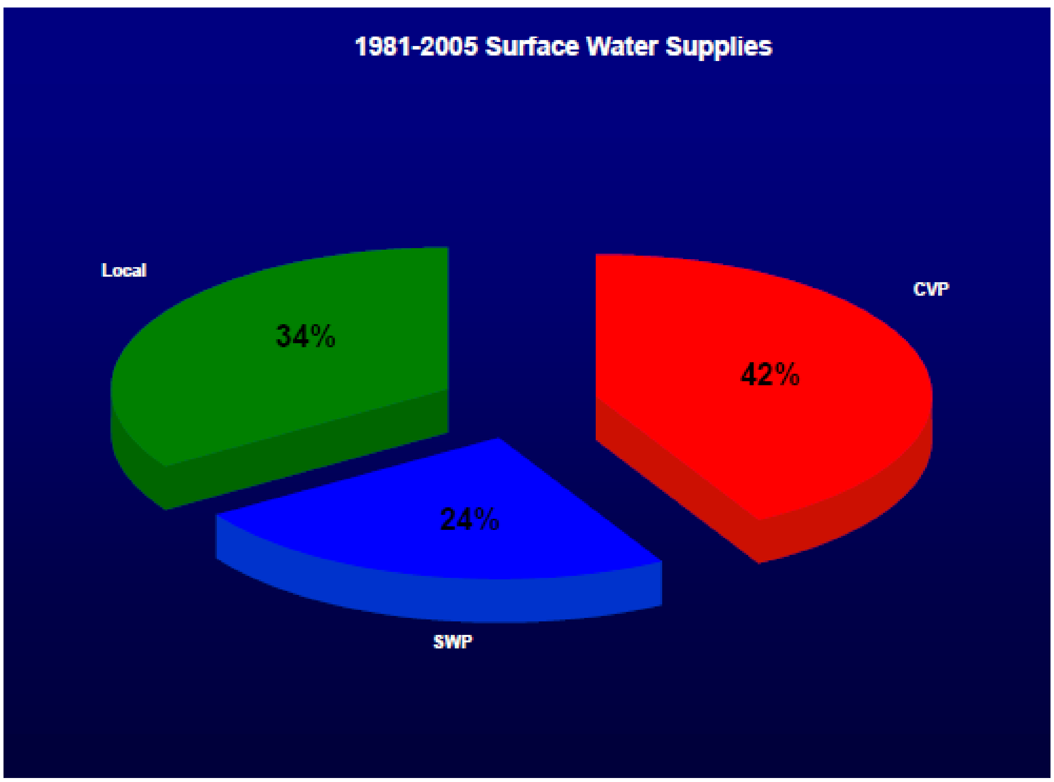


Figure 3. Proportions of Local and Imported Water Supplies.
(Poso Creek RWMG, 2007)

The total surface water diversions from all sources to the Region from 1981 through 2005 are shown in Figure 4. This 25-year period was selected as a baseline for analyses performed for the Operations Model developed for the Poso Creek IRWM Plan. This model analyzed historical water deliveries, supply, demand, and spreading. The annual surface water diversions to the area varied from less than 400,000 acre-feet per year to over 1,000,000 acre-feet per year. The average over the period was 775,000 acre-feet per year (Poso Creek RWMG, 2007). A combination of hydrological, environmental, and regulatory constraints are affecting conveyance and reliability of surface supplies delivered to the Region, which results in a projected decrease of the three principal sources of surface water delivered to the Region in comparison to historical supplies (DWR, 2008).

Also illustrated in Figure 4 is the annual variation from the average groundwater level changes for the Region. The average groundwater level change over the 25-year period is represented on the secondary y-axis as 0 feet. During this 25-year period (1981 through 2005) average groundwater levels for the Region, which drop in the dry years, have been able to recover to near pre-drought conditions in the wet-periods indicating a long-term positive balance between supplies and demand in the Region. (Poso Creek RWMG, 2007)

The operating range of the basin over the 25-year period is outlined by red dotted lines. By observation of the water level fluctuations for the Region and the Operations Model, it is estimated that the groundwater basin in the Region stores approximately 100,000 acre-feet of water for every 10 feet of water level change. There is approximately a 50-foot difference between the lowest groundwater level and the highest in the 25-year study period. No significant impacts to the groundwater basin occurred during this period. Therefore, at a minimum, an estimated 500,000 acre-feet of usable storage is available in the groundwater basin when the groundwater is at the lower limit.

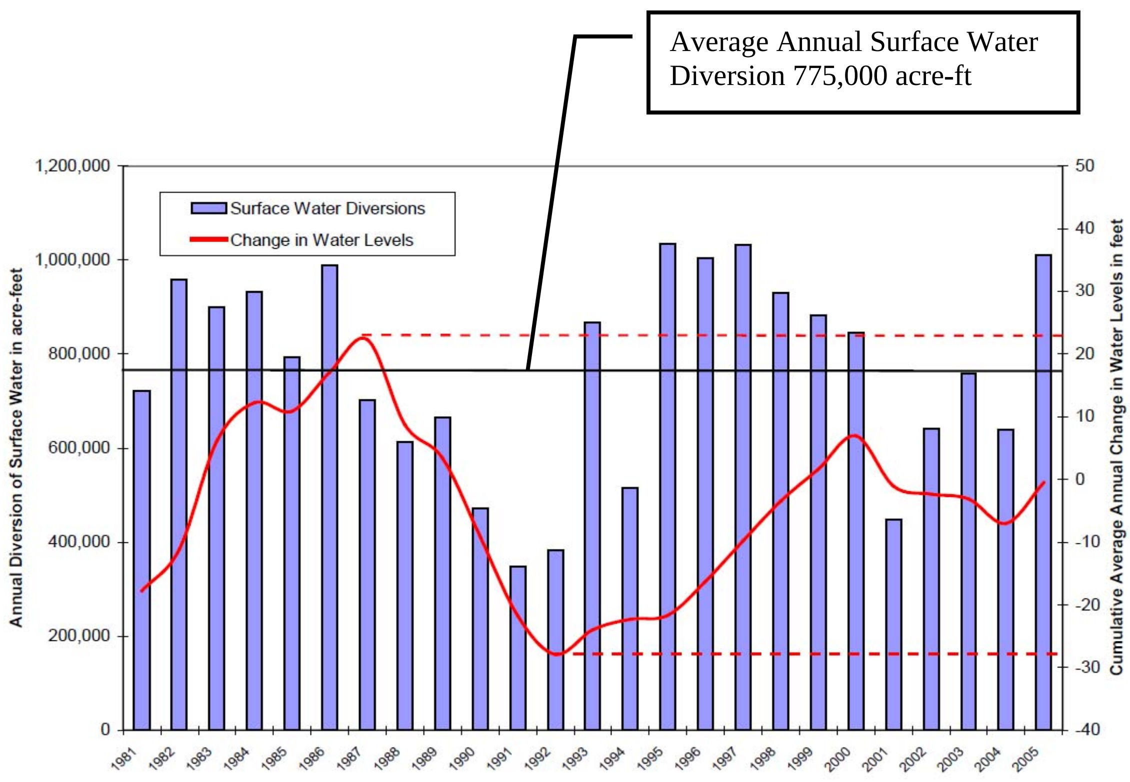


Figure 4. Historical Surface Water Diversions and Average Change in Groundwater Levels

PURPOSE AND NEED FOR PROJECT

Water supply reliability and sustainability of the common groundwater basin within the Region are being impacted by changing dynamics of water supply timing and availability, such as:

- ✓ Environmental and water quality regulations, including Court-ordered actions;
- ✓ Increased urbanization resulting in reductions in water available for agriculture; and
- ✓ Changes in weather patterns associated with climate change.

While the *common groundwater basin* is the reason that all overlying uses will feel the impact, it is also the reason that anything that is done to mitigate declines in water levels, such as projects identified in the Poso Creek IRWM Plan, will benefit all uses. The *need* for a water supply enhancement project for this Region (Project) is to respond to these projected reductions in water supply as illustrated in Figure 5, below.

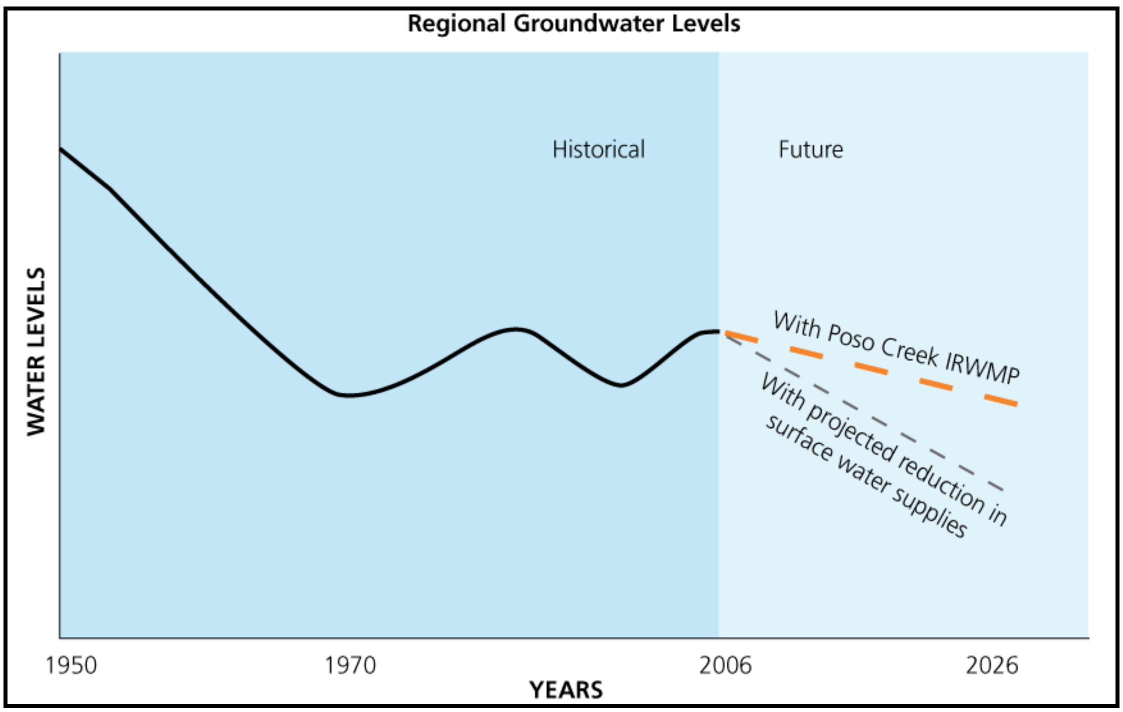


Figure 5. Challenges to the Region: Historical and Projected Groundwater Levels

The results of the Operations Model identified that future surface water supplies delivered to the Region were anticipated to decrease as compared to the recent 25-year historical period analyzed in the Poso Creek IRWM Plan. As a result of this future surface water supply uncertainty there would be an inherent decline in the average groundwater levels in the Region. To help offset this anticipated decline, the Poso Creek IRWM Plan identified non-structural and structural projects to limit the projected impact.

Implementing these identified projects will enhance the water supply reliability and conserve groundwater for the Region.

Therefore, the *purpose* of the water supply enhancement Project is to make the necessary non-structural and structural changes that allow for the Plan participants to reduce surface water supply losses by recharging the aquifer at the time the surplus surface water supplies are available. Implementing the Project would enhance storing of the surface supplies in a district which has capacity to absorb the supplies when they are available. Recharge can be performed by the following methods:

- Using direct recharge by delivering water into recharge ponds, and
- Using in-lieu recharge by delivering surface water for irrigation, thereby reducing pumping of groundwater.

When the Poso Creek IRWM Plan was completed in 2007, the Participants were capable of absorbing over 1 million acre-feet in a calendar year. As the structural and non-structural projects of the Poso Creek IRWM Plan are implemented, it will increase the absorptive capacity within the Region. Based on the findings of the Operations Model presented in Chapters 4, 5 and 7 of the Poso Creek IRWM Plan, *even if all structural and non-structural components of the Poso Creek IRWM Plan were implemented*, the Region would not be able to fully recover the loss of water supply unless a solution to the Sacramento-San Joaquin Delta pumping restrictions were developed (Poso Creek RWMG, 2007).

WATER SUPPLY ENHANCEMENT PROJECT

The Water Supply Enhancement Project components, shown in Figure 6 and listed in Table 2, will provide the districts within the Region operational flexibility to help adapt to water management constraints and maximize the use of their contract water supplies and other supplies that may be available from time to time. In particular, the Project provides the means for coordinating the assets, needs, and operations of the districts within the Region, with the end result being improved *water supply reliability and conserved groundwater*.

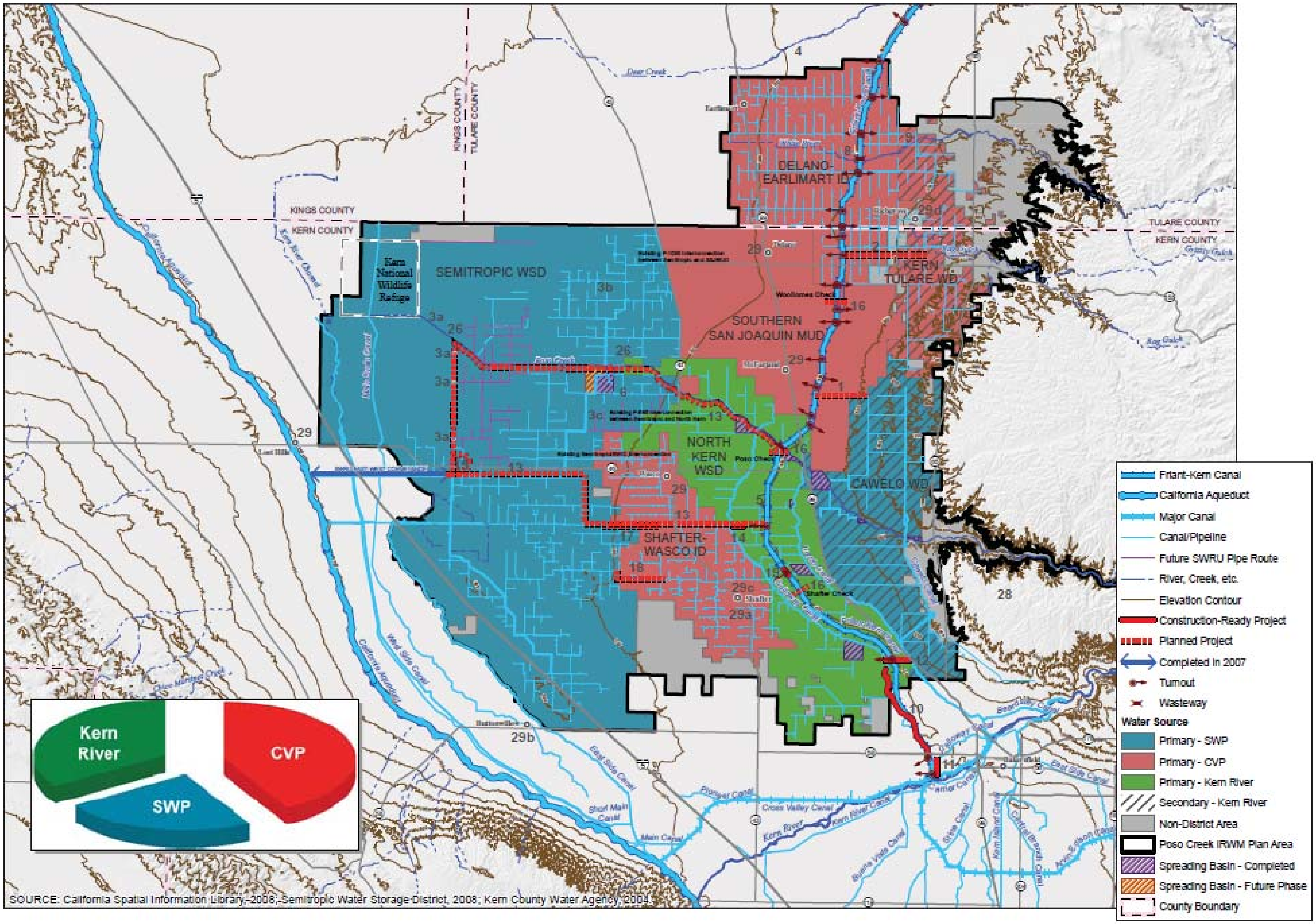


Figure 6. Water Supply Enhancement Project for the Poso Creek IRWM Plan Region

Table 2. Poso Creek IWRM Plan Projects

P = In Progress; C = Construction Complete
D = Planning/Preliminary Design; S = Shovel-Ready for Construction
(outlined) = Federal funded ($); (shaded) = Potential State or Federal funding

Structural Projects (Locations Shown on Map)

Updated January 2010

Expand In-Lieu Service Areas

D	1	Connect Friant-Kern Canal Turnout to Cawelo's North System
D	2	Ninth Avenue Pipeline
S	3a	**Stored Water Recovery Unit ($917K)** In-Lieu Service Area Facilities Well Field Recovery Facilities & HCP
C	3b	Expand P-1030 In-Lieu Service Area
C	3c	New P-565 In-Lieu Service Area

Expand Direct Recharge

D	4	G-W Banking North of DEID with Pixley ID
D	5	G-W Banking Conveyance Improvements to North Kern WSD Recharge and Recovery Facilities; Additional Friant-Kern Canal Turnout and Groundwater Recovery Wells
S	6	**Pond Poso Spreading Grounds ($2.2M)**
D	7	Rag Gulch G-W Banking Project
S	8	**Turnipseed GW Banking Project Enhancement along White River in DEID ($1.55M)**
D	9	White River G-W Banking in Rag-Gulch

Modify Conveyance Systems

S	10	Calloway Canal Improvements
S	11	**Calloway Canal to Cross Valley Canal Interconnection**
S	12	**Calloway Canal to Lerdo Canal Interconnection ($5M)**
D	13	Multi-District Conveyance Facility
S	14	**North Interconnection between North Kern WSD/Shafter-Wasco ($300K)**
D	15	Pilot Arsenic Treatment Plant
D	16	Reverse Flow in the Friant-Kern Canal
D	17	Shafter-Wasco/Semitropic Interconnection on Kimberlina Road
D	18	Shafter-Wasco/Semitropic Interconnection on Madera Avenue
S	19	**South Interconnection between North Kern WSD/Shafter-Wasco**

Non-Structural Projects (some locations not shown on map)

P	20	**Energy Usage**
P	21	Joint Powers Authority
P	22	**Institutional Agreements and Governance for IRWMP Implementation ($300K)**
P	23	**GW Banking for Parties Outside of Poso Creek IRWMP Region ($5M)**
P	24	Optimizing Region's Pumping Lifts
P	25	**Enhance Groundwater Monitoring and/or Modeling**

Enhance Environmental Resources

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

Enhance Flood Control

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

Assist Economically Disadvantaged Communities

D	29	**Enhance Water Supply, address Drinking Water Treatment Needs, and upgrade Waste Water Treatment Facilities (~$7M)**

- The *findings and conclusions* of the Poso Creek IRWM Plan include …

    - The Region has a water supply problem (with the projected long-term average annual reduction in surface water supplies projected to be over 100,000 acre-feet of the 775,000 acre-feet per year delivered into the Region during the period 1981-2005).

    - By the individual districts working together to operate as a Region, the problem can be reduced but not eliminated; Regional solutions, based on currently available supplies, will be limited in effectiveness until a solution to the Sacramento-San Joaquin Delta is achieved.

    - Project priority is given to enhancing conveyance between districts within the Region that increases absorptive capacity and operational flexibility so wet-period water can be delivered when it is available.

    - Both non-structural and structural measures are required.

- Implementation of the Project for the Poso Creek IRWM Plan includes...

    - **Non-structural measures being implemented**:

        - An organizational structure and environmental compliance framework that allows for banking and exchange approvals to be in place to take advantage of unregulated and unscheduled water supplies that are available from time to time, often on short notice (This means a pre-approval CEQA/NEPA documents for expediting approval of banking and exchange agreement among districts within the Region).

        - The framework that allows districts to form agreements to deliver their water supplies into the Region to maximize the utility of the Region's assets and thereby maximizing water supply and reliability to the Region (This is being accomplished by a monthly meeting framework that allows banking and exchange agreements between districts to be formed quickly and make use of the CEQA/NEPA expedited approval process for the Region).

        - A means of maintaining equity between districts within the Region, in terms of water and/or dollars (Presently, the districts continue to meet monthly and utilize their cost sharing mechanism of their MOU for the Region; in the future this could be used as a mechanism to raise local funding for projects, including participation from non-agricultural users).

- **Structural measures being implemented:**

  - *Conveyance Improvements* to deliver CVP supplies from the Friant-Kern Canal to non-CVP districts who have direct and in-lieu recharge capacity.

    - Interconnect North Kern and Shafter-Wasco to increase exchange capacity of CVP supplies.

    - Interconnect the Calloway and Lerdo canals to allow CVP and SWP contract supplies to be banked in North Kern and/or Cawelo.

    - Additional turnout capacity from Friant-Kern Canal to North Kern.
    - Enhancements to Poso Creek channel that improves conveyance of Friant-Kern CVP water into Semitropic, North Kern, and Cawelo.

  - *Absorptive Capacity Improvements* for banking wet-period supply by increasing the capacity for direct and in-lieu recharge and recovery facilities. Table 3 identifies the existing facilities and spreading basins under construction that are being added to increase the absorptive capacity during the "shoulder" months of the irrigation season when agricultural demand is lower.

  - *Flexibility in Absorbing Supplies* for all districts that receive delivery of SWP and CVP supplies delivered from the CA Aqueduct by interconnecting the Cross Valley Canal and Calloway Canal.

  - *West-to-East conveyance improvements* to enhance the return capacity ability of the Region to complete banking and exchange agreements that involve delivering CA Aqueduct supply for Friant-Kern Canal supply.

    - Interconnections between Semitropic and Shafter-Wasco; enhance an existing and consider new interconnections.

    - Interconnections between Semitropic and North Kern.

    - A Multi-District Conveyance Facility capable of bi-directional, direct delivery of water, up to 300 cfs, between the CA Aqueduct and the Friant-Kern Canal.

Table 3. Recharge, Storage and Recovery Facilities Capacity

Districts	Recharge Capacity				Recovery Capacity	
	Spreading Basin(s)	**Recharge Rate (ac-ft/day)**	**Fill Rate (cfs)**	**Spreading Ground Capacity (ac-ft/yr)**	**Instantaneous (cfs)**	**Annual (ac-ft/yr)**
SWSD	Pond-Poso (in construction)	250	370	65,000	105 (district wells) 705 (landowner wells)	66,000
SWID	none					
NKWSD	5 sites	720	363	300,000	200 - 300 (estimated)	80,000 (historical) 200,000 (theoretical)
DEID	Turnipseed (in construction)	50 - 60	25 - 30	TBD	TBD	TBD
KTWD	none					
CWD	1 site	160	80	65,000	40	29,000

Notes: 1. Data includes capacity for existing and proposed spreading grounds.

PROJECT IMPLEMENTATION AND ACCOMPLISHMENTS

The RWMG continues to meet monthly under a Memorandum of Understanding to implement the Water Supply Enhancement Project identified in the Poso Creek IRWM Plan. During the Plan formulation and monthly implementation discussions, two common themes emerged:

- A sense of shared responsibility on the part of the member districts of the RWMG for sound stewardship of the Region's surface water and groundwater resources, and
- Recognition that water supply challenges facing this Region may only be solved through regional collaboration and cooperation with neighboring districts, San Joaquin Valley planning efforts, such as the California Partnership for the Southern San Joaquin Valley, and state and federal agencies who are responsible for oversight of the Sacramento-San Joaquin Delta.

The RWMG recognizes that water management improvements and institutional changes will take time. The RWMG also recognized the projected loss of surface water supply to the Region has accelerated the need for regional management in order to off-set losses and avoid future conflicts. This is the driving force that has brought the districts together and is the shared focus as they implement the Water Supply Enhancement Project.

The district managers are gaining trust and experience by meeting regularly to discuss regional water management operations under both wet-year and dry-year conditions. The result of this dedicated communication is a collection of water management strategies that are being implemented as funding permits. Recent funding accomplishments are identified in Tables 2 and 4.

The RWMG has also made progress on removing institutional constraints that, once achieved, would gain back 16,000 acre-feet per year of the projected loss, based on the Operations Model. The modeling also indicated that even with all projects implemented, only about 40-percent of the average annual shortfall of over 100,000 acre-feet may be recovered unless there is a Sacramento-San Joaquin Delta solution, thus, limiting the effectiveness of local solutions to this challenging water supply problem.

Table 4. Recent Funding Accomplishments

District	PROJECT NAME	Funding Source	YEAR OF AWARD	AWARD AMOUNT
Integrated Regional Water Management Plans				
Semitropic Water Storage District	Poso Creek Integrated Regional Water Management Plan	State	2005	$499,435
Semitropic Water Storage District Lead Agency	System Optimization Reivew for the Poso Creek IRWM Plan Area	Federal	2008	$300,000
Conjunctive Use				
Delano-Earlimart Irrigaion District	Turnipseed Groundwater Bank - Phase II	Federal	2009	$300,000
Delano-Earlimart Irrigaion District	Turnipseed Groundwater Bank - Phase II	Federal	2009	$1,000,000
Shafter-Wasco and North Kern Water Storage District	Water Banking Improvement Project	Federal	2009	$300,000
Kern-Tulare Water District	South Interconneciton between North Kern WSD and Shafter-Wasco ID	Federal	2009	$0
Semitropic WSD	Pond-Poso Spreading and Recovery Facility	Federal	2009	$2,222,660
Semitropic-Rosamond Antelope Valley Water Bank JPA	Antelope Valley Water Bank Initial Recharge and Recovery Facility Improvement Project	Federal	2009	$5,000,000
North Kern WSD	Calloway Canal to Lerdo Canal Intertie	Federal	2009	$5,000,000
Cawelo Water District	Cross Valley Canal to Calloway Canal Intertie	Federal	2009	$0
Semitropic WSD	Planning, Design, and Permitting the Stored Water Recovery Unit of the Semitropic WSD GW Bank	Federal	2010	$917,000
Groundwater Management/AB303/Local GW Assistance Program				
Delano-Earlimart Irrigation District	Groundwater Monitoring Improvments	State	2008	$250,000
North Kern WSD	North Kern Groundwater Monitoring Program	State	2008	$250,000
Semitropic Water Storage District	Regional Subsidence Monitoring	State	2005	$220,000
Semitropic WSD	2005 Groundwater Monitoring Improvement Project	State	2005	$218,141
Semitropic WSD	2008 Groundwater Monitoring and Management Improvement Project	State	2008	$0
Total Funds Awarded				**$16,477,236**

SUMMARY

Districts within Poso Creek IRWM Plan Region of the Southern San Joaquin Valley are faced with re-regulating their local, state, and federal water supplies in an effort to reduce the impacts on their common groundwater basin. These districts are concerned with maintaining water supply reliability as they respond to the following issues:

- Court-ordered reductions on pumping South of the Sacramento-San Joaquin Delta,
- San Joaquin River Settlement, and
- Restrictions on Kern River water.

All of these concerns lead to a projected loss of surface water supply to the Region as compared to their historical use of supplies. These concerns have also led to the RWMG implementing this Water Supply Enhancement Project based on the findings of the Poso Creek IRWM Plan.
Implementing the Project requires an increased capital outlay for modifying and adding infrastructure needed to manage district water supplies differently than in the past. Recently, the districts were successful in receiving Federal funding assistance through Reclamation's Challenge Grant Program and they will continue to implement the Project as local, State, and Federal funds are available.

REFERENCES

Poso Creek Regional Water Management Group, July 2007. Semitropic Water Storage District – Lead Agency. *Poso Creek Integrated Regional Water Management Plan.*

“FRAMEWORK” FOR THE SAN JOAQUIN VALLEY INTEGRATED REGIONAL WATER MANAGEMENT PLAN

Sargeant J. Green[1]

ABSTRACT

The California Partnership (Partnership) for the San Joaquin Valley (Valley) commissioned the California Water Institute (CWI) at California State University, Fresno to develop a “framework” for a long-term San Joaquin Valley water management plan. This paper describes the work of CWI to develop the “framework” and its findings.

INTRODUCTION AND BACKGROUND

Purpose and Scope of the “Framework”

Water is the lifeblood of the San Joaquin Valley. In the past fifteen years the competing uses for water have resulted in redirection of surface water supplies away from the Valley and have intensified the use of Valley groundwater. The Valley’s challenge is to become much more creative to deal with the natural cycles of drought and excess as well as the permanent and temporary losses. The importance of water will require a more thorough evaluation of our assets and needs, and our stewardship of local supplies. The California Partnership for the San Joaquin Valley recognized the need for an assessment of our water environment and commissioned a “water work group” consisting of a Partnership “convener” (Supervisor Ray Watson of Kern County), the California Water Institute at CSU Fresno and a “water policy working group” (key Valley interests) to develop a framework for analyzing the Valley water issues, water inventory, future water needs and to develop a potential menu of water management solutions. The following report presents that framework.

The San Joaquin Valley is comprised of portions of the 8 counties of Kern, Tulare, Kings, Fresno, Madera, Merced, Stanislaus and San Joaquin (Figure 1) with 62 cities and more than 3.4 million residents, and has a long history of contributions to the success of California. Although it is recognized worldwide as an agricultural powerhouse and is one of the fastest growing regions in the nation, it is also one of the most economically challenged in comparison to the rest of the state and nation.

Governor Arnold Schwarzenegger established the California Partnership for the San Joaquin Valley by Executive Order in June 2005 in an unprecedented effort to focus attention on the needs of the region. As the Governor stated in the Executive Order, “The strength of California is tied to the economic success of the San Joaquin Valley.”

Through the year 2030, the growth rate of the region is projected to be 65% higher than the state average. How effectively the region accommodates the growth will be an important determination of California’s future.

[1]Project Director, California Water Institute, 6014 N. Cedar Ave., Fresno, CA 93710

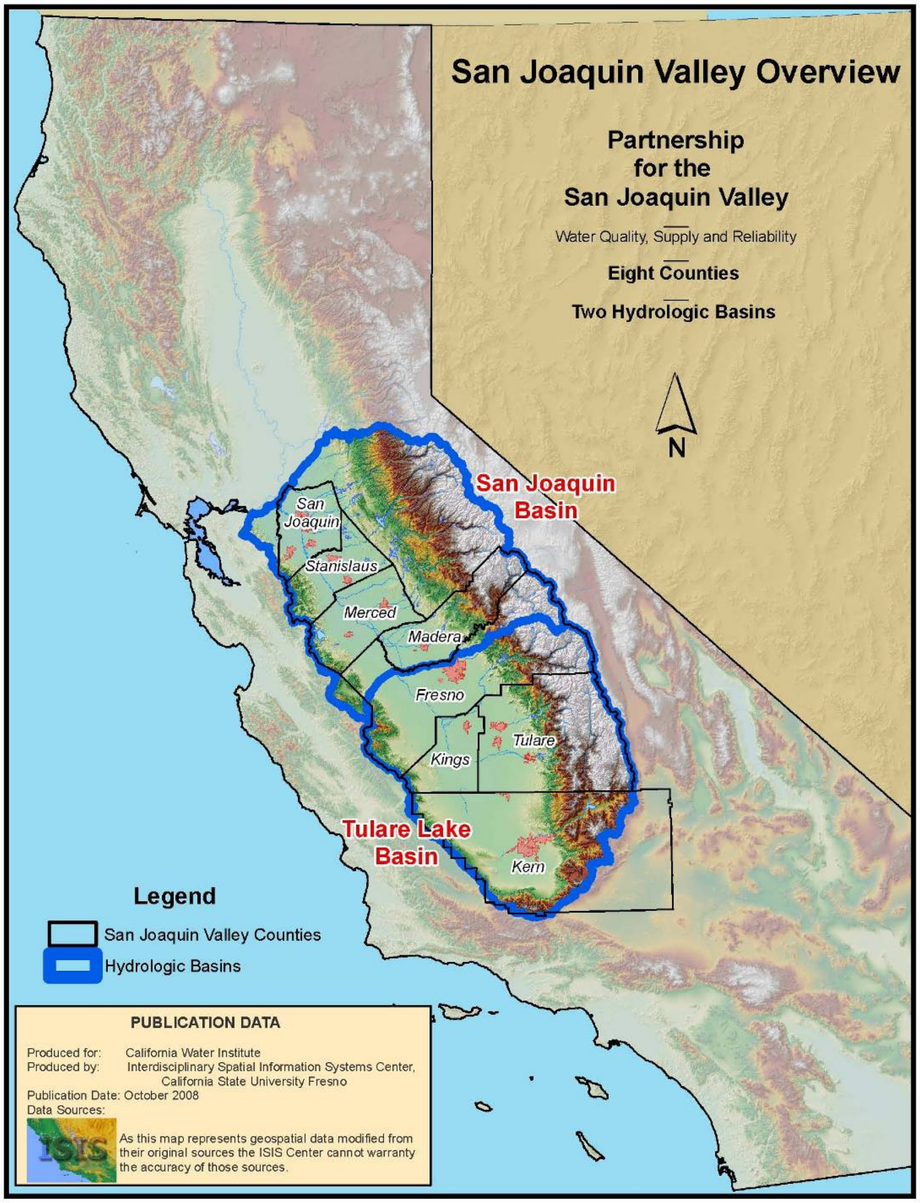


Figure1. The Eight San Joaquin Valley Counties

The Strategic Action Plan - "*The San Joaquin Valley*: *California's 21st Century Opportunity*" - sets forth overall strategies and specific actions with accompanying indicators to measure progress. It builds on the existing strengths and addresses current challenges to achieve a Prosperous Economy, Quality Environment and Social Equity, the "3E's" of sustainable growth. It embraces and enhances the assets that define the region, such as the San Joaquin River and Highway 99, as leading strategies to attract investment. It recognizes the Valley's heritage of agriculture as the foundation for economic growth and forges new frontiers for prosperity by identifying five key industry clusters for development: (1) agribusiness including food processing, agricultural technology, and biotechnology; (2) manufacturing; (3) supply chain management and logistics; (4) health and medical care; (5) renewable energy.

The detailed reports and recommendations are integrated into six major initiatives with associated indicators that will be tracked annually:

1) Grow a Diversified, Globally-Competitive Economy Supported by a Highly-Skilled Workforce
2) Create a Model K-12 Public Education System
3) Implement an Integrated Framework for Sustainable Growth
4) Build a 21st Century Transportation Mobility System
5) Attain Clean Air Standards
6) Develop High-Quality Health and Human Services

The Strategic Action Plan calls for a sustained public-private partnership over the next decade to mobilize the essential government and civic leadership to achieve measureable results. The Strategic Plan and organizational structure were approved by the Governor and funded by the Legislature for an initial term of two years with the intent that State legislation would then be enacted to ensure commitment and continuity for the full decade. The overall goals of the Partnership, linkages and inter-relationships are symbolized by the following figure (Figure 2):

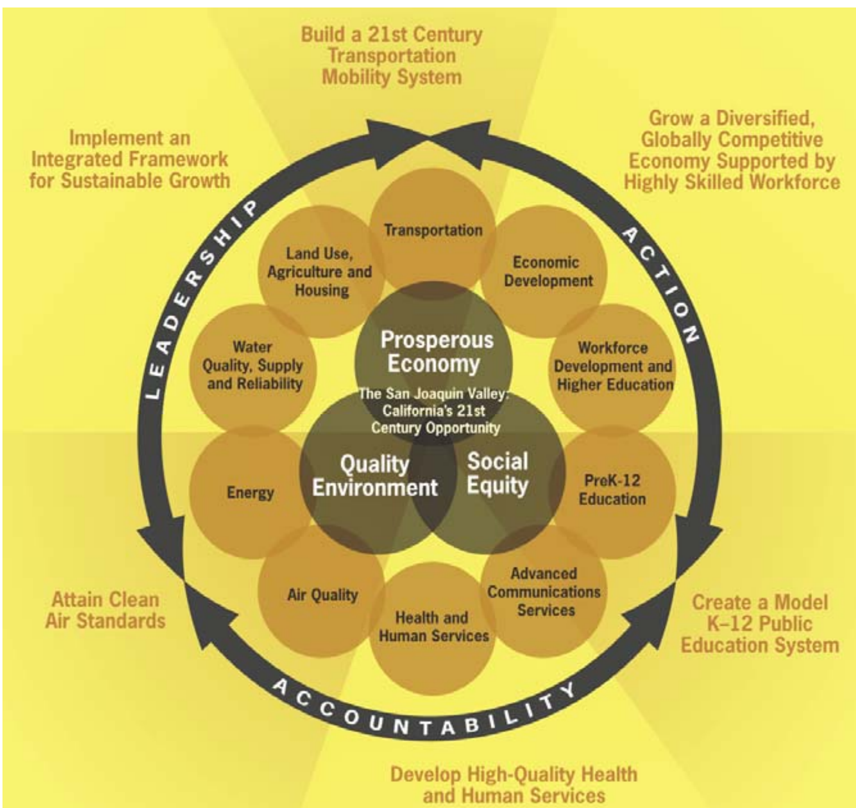


Figure 2. The Partnership Linkages and Inter-Relationships

Water Quality, Supply and Reliability Water Work Group

The growing population and expanding economy of the San Joaquin Valley require an adequate water supply of sufficient quality and reliability for all sectors as well as for the environment. The current supply is inadequate for the future and there is significant annual groundwater overdraft that must be reversed. In addition, the San Joaquin River is a valuable natural asset that needs to be restored and protected while developing additional water supplies. Solutions must embrace efficient water use practices, construction of additional facilities for both surface and groundwater storage and reusing waste water.

Prior to the establishment of the California Partnership, four San Joaquin Valley Congressional delegation members initiated the development of the San Joaquin Valley "Regional Water Plan" and enlisted the services of the California Water Institute (CWI) at California State University, Fresno to facilitate the planning effort. The California Partnership determined that the two water planning efforts were congruent and that the public interest would be best served if the two efforts merged. Four resource management strategies were identified as a foundation for the Congressional Regional Water Plan. More strategies could be added as needed later. The four strategic areas identified were: (1) Water Supply, (2) Water Quality, (3) Flood Control, and (4) Environmental Enhancement. The Regional Water Plan is to be coordinated with state and federal planning agency efforts currently underway during the planning horizon. The result of the merger was the commissioning of the Partnership "Water Work Group" which was charged with developing a "framework" for delivering a comprehensive water management plan for the Valley.

The California Partnership Strategic Action Proposal recommended six specific water-related actions that form additional foundation elements for the subject Valley "Water Management Plan." The actions follow:

1. Develop and implement a "San Joaquin Valley" water management planning process that covered all eight counties (the federal effort was limited to seven)

2. Incorporate major levee enhancements in the Sacramento-San Joaquin Delta and San Joaquin Valley to safeguard regional water quality and water supply as well as provide for flood control

3. Augment surface and groundwater banking programs and recycled water projects in the San Joaquin Valley

4. Improve water quality and expand salinity management infrastructure development

5. Promote environmental restoration

6. Expand agricultural and urban water use efficiency and energy efficiency programs

<u>What is the "Framework"?</u>

The Partnership selected the California Water Institute (CWI) to deliver the analysis of what would be necessary to develop a fully mature "San Joaquin Valley Water Management Plan" and to serve as staff and technical advisors to the Water Work Group. The Water Work Group convener selected by the Partnership, Supervisor Ray Watson of Kern County, also sought input on the Valley's current water events menu which assisted in an "outline of activities" for the Group and the CWI, by identifying some of the core issues and a strategy that he believed would serve as a model process to move the eight Partnership counties forward together in water management solutions. Two dominant events prevailed in crafting the strategy. The first was a series of legal rulings that resulted in a Delta water delivery crisis; the second was an unfolding drought. The result was the development of a dual process that is likely to be replicated in the longer-term planning efforts. The two processes involve; (1) the implementation of a careful and deliberative analysis of assets and liabilities for the development of a "water management plan" for the Valley, and; (2) an adaptive strategy to deal with crisis issues that invariably arise in either the physical water world or as a matter of policy.

The result of the above was the following "framework" report which encompasses both the fundamental outline of how to proceed to develop the information needed for various levels of water management planning (regional, inter-regional, hydrologic basin, Valley) as well as the use of the aforementioned adaptive strategies to move more critical water management (such as groundwater banking and rural water systems) and policy issues (for example, Delta conveyance and Delta ecosystem management) forward as they arise from the crucible of conflict or scarcity.

THE VALLEY WATER PLAN FRAMEWORK

<u>The Assessment Process</u>

The recommended assessment process involves organizing and conducting a careful and deliberative activity of analyzing the water environment assets and liabilities for every area of the San Joaquin Valley. The analysis must include the condition of the entire water environment including but not limited to: (1) surface and groundwater, (2) flood control and flood management, (3) water quality and (4) understanding the water needs of the ecosystems in the Valley. The organizational tool proposed to be used for that assessment is the "***integrated regional water management planning***" (IRWMP) activity now imbedded in the California Department of Water Resources, "California Water Plan" (an every-five-year-interval water assessment and planning process). Not only does the State "Water Plan" host this effort (it is also in California statute) but the recent California voter-approved water and environmental "Bond" issues have linked the availability of grant funds to the integrated planning process. Whether a city, county, local water entity or special environmental interest gets any State Bond (50 and 84) grant funds is now dependent on whether they are a part of an IRWMP.

What is "integrated regional water management planning" and why should the Partnership embrace it as the organizational and assessment tool for addressing water issues in the San Joaquin Valley? Integrated regional water management plans are "bottom-up" collaborations that are locally-driven by common interest and geography. Many are based on shared sources of water for supplies; others are based on natural watersheds. These efforts offer the opportunity for local entities that heretofore were either dependent on others for water sources or management or, even if totally independent, to interact in a way that potentially is synergistic. The potential outcome of all parties working together is likely to be more enduring management solutions.

An example of these collaborative efforts can involve cities and agricultural water agencies that withdraw water from the same groundwater aquifer. Until recently, it has been relatively uncommon for two such different agencies to work together to manage the same groundwater body optimally. An IRWMP provides a better vehicle for doing so. Sometimes the interactions are at first contradictory or competitive. However, ultimately the opportunities to work out such issues are far more palatable than fighting in an arena (court-mandated adjudication of shared groundwater in the above example) that could be detrimental to both parties. The process also brings together new partners and issues that cut across other subjects in the Partnership "circle of goals" (see diagram above). For example, energy and land use are critical components of any successful water planning effort. Energy pumps/moves water and land use determines where and how much water is used or disabused (water quality impacts). They are therefore integral discussion, assessment, quantification and solution activities for any water planning effort.

The Water Work Group, through the CWI, has been actively participating and assisting in the development of IRWMP groups up and down the Valley on behalf of the Partnership. This activity is documented in a CWI supplementary report in the CWI web site (San Joaquin Valley Regional Water Plan). Much of the Valley is now covered by IRWMP's. Several started before the commissioning of the Partnership itself. They formed under earlier guidance from the California Department of Water Resources which is still adapting the process. ***The difference is that the first IRWMP's began with a focus of analysis that most quickly resulted in building "projects" (many of which are undoubtedly needed). The newer version of the IRWMP process demands a broader assessment and more diverse participation. That diversity and added complexity demands a clear process map so as to allow the analysis of water conditions and needs to move forward more sensibly. The proposed Valley process is a further adaptation of the various preceding activities.***

The Partnership Water Work Group believes that presenting a simplified process that involves using a core menu of tools will bring consistency and reliability and hence greater success in coordinating the IRWMP groups in the Valley. The goal is to present an outline that anyone using or involved with water can adapt to develop the necessary basic information that will plug into the IRWMP plan. The process is also scalable; the tools can be used successively for larger geographic integration activities. In fact, a major goal of the proposed core assessment activities is to elevate the local groups into the next steps of the process, integrated inter-regional plans, hydrologic basin and then the Valley-wide plan. Inter-regional plans give the partner collaboratives within a geographic area an opportunity to work at the next level of synergy. An example of this is the San Joaquin River Basin, from the headwaters to the Delta confluence with the Sacramento River. Some problems with water sources, water management or the environment may require larger areas of participation that could bring more solutions and resources to apply to the water management issues associated within that hydrologic area. After building the area-wide collaborations, a Valley-wide plan can address even larger internal and external issues that determine the whole Valley's success in its water management goals.

The key to success in the planning process is to find issues of common interest to work on first. Such a problem-solving exercise will allow for the future resolution of the more difficult issues. Nonetheless, as mentioned previously, certain crises may demand a different level of attention that prevails over the deliberative process. The Partnership must remain cognizant of those circumstances and the Water Work Group will propose an ongoing mechanism for meeting those challenges such as has been employed during the recent Delta environment and drought crises.

The four core components of the proposed Valley process are:

1. ***The organizational activity and a preliminary assessment tool – involves the logical partners and institutional formation of local IRWMP's. The formation activity occasionally involves partners who have not necessarily had the best relationships before or possibly no relationship at all; therefore, initial formation is often a third-party, facilitated process. The assessment tool includes the initial inventory of water environment issues, assets and liabilities with stakeholders and partners. The process is as inclusive and as broad as possible so that the optimum opportunities for sustainability and integration can be realized.***

2. ***The budget tool – the total water environment budget is calculated for current reasonable uses of water and for various futures (the Work Group recommends 50 years) so as to assist with developing a "potential solutions" matrix to meet or decide how to deal with water budget issues.***

3. ***The solutions matrix – IRWMP groups will develop water management tools to match the current and future needs for water with the options available for meeting those needs. The solutions tool must also include a technical, institutional and financial capacity assessment for the various proposed alternative water needs and use conditions.***

4. ***The Partnership water crisis response – a deliberative process assists in the development of longer-term sustainability strategies, however, the water environment is increasingly faced with crisis events that call for extraordinary measures and actions. The process envisioned here is to institutionalize an "action team" response of the Partnership membership that can attempt to find solutions and policy convergence on crisis issues within competing interests of the Valley. The process involves gathering the appropriate parties in a collegial atmosphere where quick, rational assessments and recommendations can be developed to prevent, mitigate or***

solve such crises or join larger efforts to deal with the water management issues.

The Water Work Group believes that every area in the Valley needs to become part of an IRWMP and follow the above process for development of a "Water Management Plan" for their designated area. Where there is a reluctance on the part of potential local or regional responsible partners, the Work Group recommends the Counties act as the agent (with all due deliberation on the costs and impacts of such decisions) for areas without coverage in an IRWMP so there are absolutely no gaps in Valley coverage. Such coverage is critical in addressing the Bond funding mechanisms mentioned previously; both the California Legislature and the administrative funding agencies have made it clear that State support will go to areas with complete coverage and the higher level inter-regional plans. The Work Group also believes that participating in a local IRWMP implies additional participation in the Basin-wide and Valley-wide IRWMP process using the same organizational and analytical tools, adapted as necessary to the conditions and limitations of each level of participation. The following are the suggested core tools that should be common to all parties participating in the Valley water management planning processes. The tools are not completely definitive or conclusive, they are meant to serve as starting points. The goal is to develop a process that is transferrable. The tools are meant to assist all water users to participate meaningfully in the process by telescoping down to the bare essentials the data needed to understand a region, basin and the Valley's water conditions and needs.

The Assessment Tool

The assessment tool involves documenting the types of water use in the geographic area of a jurisdiction within an IRWMP at the beginning of its efforts. The water-using activities fall into three main categories as follows:

1. ***Urban and Rural Domestic, Industrial and Commercial Water Use Activities***
2. ***Agricultural Water Use***
3. ***Environmental Use***

The assessment tool and the subsequent budget tool are summary presentations based on the more comprehensive "existing conditions" analysis used by the California Department of Water Resources. **Every participant in the ongoing efforts will be encouraged to use the Department's analytic tool.**

The Water Budget

With a basic understanding of the current uses of water in a circumscribed area, the next tool involves projecting the probable changes and future needs. The use patterns assume high-quality water will be required in all cases because the dominant uses are human consumption and agricultural crops which both require substantially low total salt levels. The projection also assumes principles will be established that outline what goals an area has for future land use patterns and their alternates. The principles may include items such as not giving up any further agricultural land so that agriculture remains as a significant economic driver in the Valley. An alternate strategy would include converting as much land as possible to housing and industrial development so as to fundamentally change the economy of an area or areas so a higher-income economic condition can be attained. A third alternate, or principle of future land use, is to convert as much land as possible back to natural environments and make an area's economy based on eco-tourism and hunting. Each of these alternates then needs a re-calculation of the water budget.

The Solutions Matrix

Water supply with the necessary quality appears to be the over-riding issue in the San Joaquin Valley. Flood protection, while important, is already a somewhat separate activity under the auspices of the separate "Bond" issue, "Proposition 1E". Therefore, the Water Work Group believes the focus of a core solutions strategy has to be water supply and quality for the budgeted uses. Local versions of the solutions matrix can add the flood protection element. Flood management is important in the solutions process because better utilization of wet year supplies will be an important element of the water budget.

The solutions involve not only the water budget under various alternative futures but also whether there is water available to meet the various alternates. Impacts from natural events such as long-term climate change reducing snow pack could significantly reduce water availability. If the water needs of some alternates cannot be met at each level of analysis, local, basin and Valley, then new additional future land management alternates will have to be constructed and the water availability will dictate that structure. The following matrix is a simplified version of the California DWR version in the proposed Water Plan 2009. Each of the alternate land management and budget tool uses will require an analysis of the potential solutions to meet the future needs. The utility of the process is the potential clear emergence of certainty of need that can then be used for leveraging the type of solutions that rise above the local capabilities to regional and state-wide levels.

Water Crisis Response

The IRWMP assessment and solutions process is a long-term project that should be used at every level of planning: local, inter-regional, basin and Valley-wide. However, it is clear from the efforts of the Water Work Group that water crises will undoubtedly occur and a response capability will remain a significant need for the foreseeable future. Three particular issues were brought to the forefront during the Partnership efforts. The first was the Delta estuary biological crash and hence, south-of-the-Delta water delivery instability, along with a drought; the second was the potential economic failure and poor quality services in small rural communities due to the high cost of operating and maintaining local water infrastructure and the third was drought-related loss of surface water supplies was accelerating the use of Valley groundwater. Our groundwater basins are now showing significant signs of stress. Groundwater is also receiving renewed attention as potentially needing State-wide regulation (Legislative Analyst's Office report, October 2008 and 2009 legislative action, "measurement" requirements). The result of these findings was the efforts by the Work Group, Tulare County and CWI to develop tools and strategies to cope with these issues. The primary tool is an "action team" approach and the Work Group recommends the Partnership formally recognize the need to continue to convene in such a manner to address such crises. These future activities will have to be convened based on the premise that if the issue is important enough to the Valley, the principals involved will find a way to convene the needed sessions.

SPECIAL STRATEGIC INITIATIVES — INTEGRATION PILOT EFFORTS

In order to explain the concepts of "integrated water management" and assist early adoption and implementation of management strategies outlined in the DWR Water Plan matrix that have a high potential for establishing important precedents, linkages and projects for San Joaquin Valley Partnership members, CWI has participated in or initiated several specific activities to pilot collaboration and integration strategies in the San Joaquin Valley. These special initiatives include:

1. *The Delta facility "water policy working group"; a facilitated process between Partnership members and other parties dependent on the Delta for exported water.*
2. *Groundwater conditions interactive map and recharge area protection mapping, a special project by CWI to demonstrate a use of GIS in implementation strategies.*
3. *Tulare County Rural Water Strategy Group support.*

The following summarizes these activities and provides links or copies of the work products if available.

The Delta Facility Process of the Water Policy Working Group

The Delta facility initiative was a special process that came out of the concern of Partnership Water Work Group convener Kern County Supervisor Ray Watson that imported Sacramento-San Joaquin Delta water that is so critical to the San Joaquin Valley was likely to be drastically reduced with the legal decisions on endangered species from the federal court in Fresno and what appeared to be a looming drought. The concerns proved to be well-founded as the water supply allocations from the Delta export facilities, the California Aqueduct and the Delta-Mendota Canal were not only substantially reduced for 2008, but rationed (limited flows, postponing delivery of allocations to the fall) during June, July and portions of August 2008 due to both court decisions and a very dry spring. The result was substantial idling of annual crop land in the western and southern parts of the Valley and an emergency declaration by the Governor for the drought-stricken areas south of the Delta.

The Delta facility process involved the selective re-configuration of Partnership representatives from both the north and south of the Valley into a "water policy working group". The membership involved the bookends on Delta water transportation positions: San Joaquin County representatives, who generally are not in favor of any new conveyance facilities that they perceive could alter their current Delta water availability and quality patterns, and the import communities south of the Delta who believe the current through-Delta water transport methods are unsustainable and causing undue significant water export restrictions and serious economic damage.

The process involved a series of monthly meetings beginning in December 2007 to try to frame the issues and needs and to develop some common ground and activities of value to both ends of the spectrum. The process continues at this time and will be the subject of special reports to the Partnership and possibly an ongoing function of the Valley Water Plan. The tentative agreement among the parties is to pursue both regional self-sufficiency (local water supply solutions to minimize Delta exports) and consensus on an optimal Delta water transportation design as co-equal activities. A summary report of the process and progress of these discussions was delivered to the Partnership Board in 2009 but no specific agreement was reached. For the Partnership effort, significant success has already been established; a north-south collaboration representing the spectrum of the San Joaquin Valley to collegially discuss how to move forward on sensitive Delta water management issues is an accomplishment in itself.

The Groundwater Interactive Map and Recharge Area Protection Strategy

One water management implementation strategy that does not appear to have any significant detractors in the San Joaquin Valley is the need to fully use our groundwater basins for water supply management and/or augmentation as well as water quality maintenance. The Valley has significant vacant space to store water in porous Valley sediments. The locations, how and which water management entities to get the water into the ground in the most efficient way possible are strategy components that are data intensive and require easily understood visualization tools to get broad support from the various possible implementation partners. A tool that is available that provides the visualization capacity is GIS (geospatial information systems). CWI's Fresno State partner, ISIS Center (Interdisciplinary Spatial Information Systems Center), has developed a GIS map to help show the condition of the groundwater system in the Valley in three dimensions and additional layers to show the recharge areas that have the soils and geology potential to quickly contribute the greatest amount of water to the underground (Figure 3). The long-term Valley Water Plan goal is to develop projects that can reduce the groundwater overdraft in the areas represented on the map or for that matter to sustain the best possible conditions in any high-use groundwater areas. The maps can also be viewed at the CWI link (San Joaquin Valley Regional Water Plan).

The soils layer is an overlay that also provides the opportunity for exploring multiple integration strategies with other Partnership and planning efforts. Specifically, CWI has advised the Partnership Land Use Housing & Agriculture Work Group (LUHA) on strategy for agricultural soils stewardship and offered strategies to the Valley Councils of Governments' (COG's) "Blueprint" efforts in land use planning to protect recharge areas. The integration strategy then is the cumulative effort to: 1) identify groundwater overdraft areas geospatially, 2) map high infiltration rate soils and geology that could be used more effectively to rapidly increase groundwater recharge in those areas, and 3) potentially protect those areas from land use changes that limit recharge capacity or inappropriate activities that can adversely impact water quality. The mapping will give water management and land use authorities a tool to require mitigation or develop other appropriate strategies for high infiltration rate areas or activities that could have significant adverse impacts on water quality on those same areas.

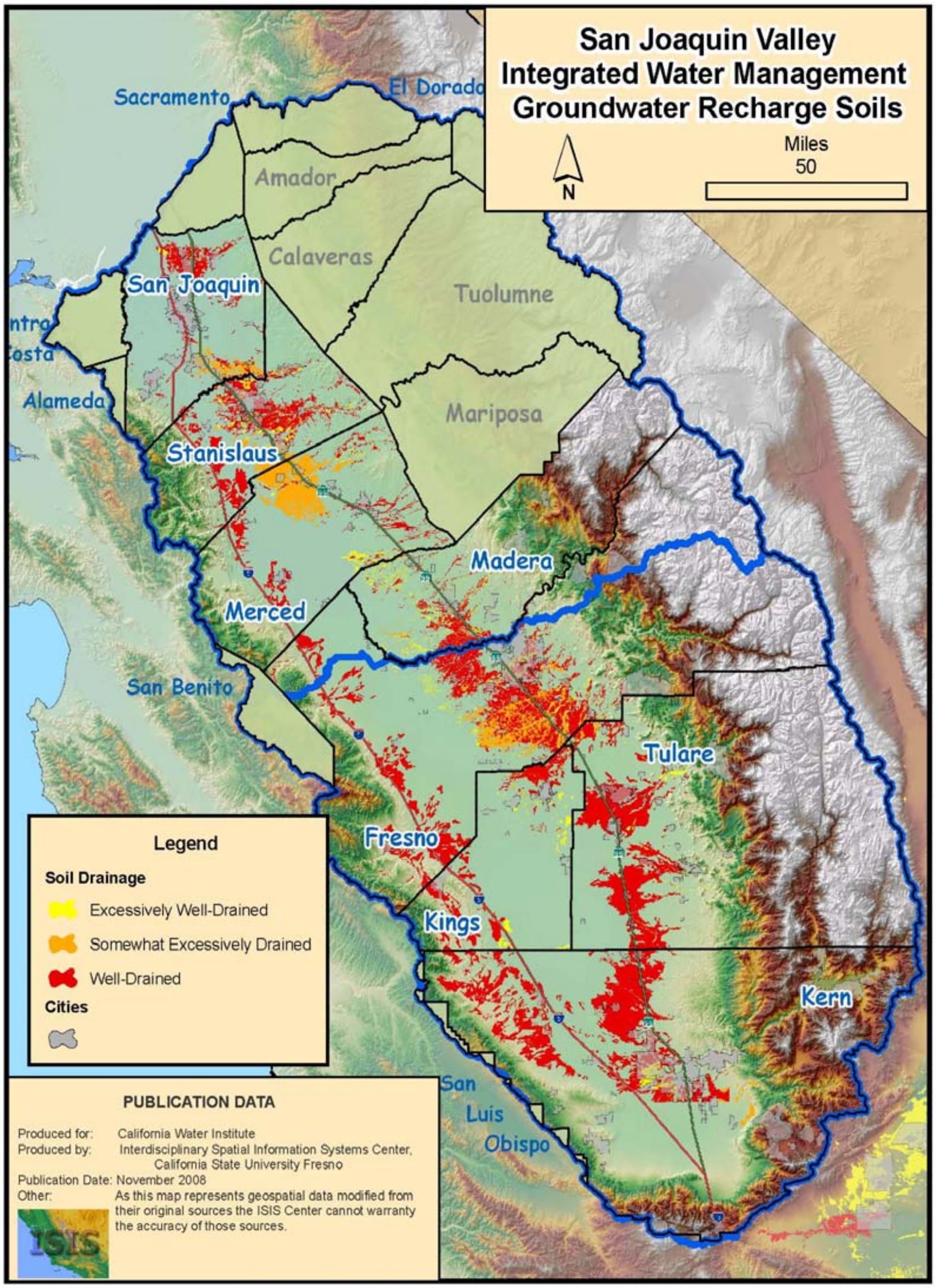


Figure 3. Well Drained Soils in the San Joaquin Valley

The Tulare County Rural Water Strategy

Tulare County has the largest number of drinking water systems in the San Joaquin Valley out of compliance with State and federal standards. Many of the systems are in disadvantaged communities. In response to this issue CWI helped organize and has participated in a "Rural Water Strategy Group" that includes a County Board of Supervisor, the State Department of Public Health Drinking Water Branch, County staff from environmental health and resources management, water system representatives and/or their consultants and other disadvantaged community service providers such as Self-Help Enterprises and the Community Water Center. The goal is to document the scope and nature of the problem and develop the technical, financial and managerial capacity to deliver safe and clean drinking water to all the rural citizens of Tulare County. One of the specific activities involved seeking financing for the collective effort which has been embodied and approved in the Proposition 84 budget expenditure plan. The concept involves integration of the drinking water and waste disposal needs of the Tulare County rural communities into the local IRWMP's and/or the Tulare (Lake) Basin Joint Powers Agreement IRWMP. The reason integration is important is because in some instances surface water from agricultural water districts are involved and groundwater may not be usable or economically treatable in some areas of Tulare County. Therefore an analysis needs to be made as to how to adequately supply various areas of the County by either surface water or economically treatable groundwater and how to effectively dispose of domestic wastewater. More arrangements for surface water use and wastewater disposal may involve more agricultural entities who are already engaged in the aforementioned IRWMP's. Furthermore, additional new requirements for Proposition 84 funding require disadvantaged communities be addressed in all the IRWMP's; the specific budget allocation from Prop. 84 passed by the Legislature and signed by the Governor will finance this integration strategy in Tulare County.

As the result of the condition of the groundwater and needs of rural systems in Tulare County, CWI also partnered with UC Merced and developed an application to the US Environmental Protection Agency for a grant to research:

4. *The viability of centralized, remote control and monitoring of water delivery and treatment systems.*

5. *Treating groundwater containing nitrates above the drinking water standards in a rural water utility well with an in-line biological treatment micro-filter.*

The proposal involves using centralized controls on remote water or wastewater systems but with access to the instant data and results of delivered water or treatment information via computer to the managers and other responsible parties such as utility district Board members. The idea is to lower overall costs with centralized management systems, yet retain local decision-making of rural utility Boards who are most directly responsible to their system constituents. The review of the application was completed and the project was not recommended for funding by the federal agency, however, the concepts will continue to be explored in any rural water management strategy and additional grant applications.

Special Partner Activities

Another significant Valley Water Plan integration component that was also sponsored by the Partnership and that bears additional emphasis and support is the Tulare Basin Wildlife Partners effort. One of the important strategic goals in all IRWMP activities and water environment management is ecosystem restoration and enhancement. Tulare Basin Wildlife Partners has developed plans to improve various habitats in the Tulare Lake Basin including wetland, intermittent wetland and upland habitats, as well as riparian corridor restoration. These activities are valuable components in any integration strategy because they not only provide important linkages to other areas of the State's complex waterfowl and wildlife systems which reduces stress (and conflict) on those systems, but they truly offer significant water management opportunities such as flood plain storage of flood waters, groundwater recharge in improved riparian corridors, conveyance connectivity opportunities, recreation locations and many other benefits. By March 2009, they completed their fourth and final Tulare Basin Regional Conservation Plan, and by October 2009, they completed a "Water Supply Strategies" report that will complement all four plans. With additional funding the Wildlife Partners could prepare a summary report on additional habitat restoration opportunities in the Tulare Basin hydrologic area. The Central Valley Joint Venture also participates in a similar process in the San Joaquin River Basin and such efforts should also be encouraged and expanded where appropriate.

THE IMPLEMENTATION STRATEGY

The Water Work Group recommended the Partnership adopt a "Resolution" encouraging all Partnership members, cities, counties, the water use and stakeholder communities continue to work to either join or continue in an IRWMP at the local level, the inter-regional level, basin and Valley-wide efforts. The Work Group also recommended the Resolution should encourage all water managers to participate in the refining and adoption of commonly-accepted assessment, water budget, and solutions processes for the local collaborative areas, inter-regional connectivity and the Valley. **The Resolution was adopted by all eight counties of the Partnership at the October 29, 2009 Board of Directors meeting.**

CONCLUSIONS AND RECOMMENDATIONS

The Partnership Water Work Group believes that water will continue to be a critical resource issue blocking the San Joaquin Valley's path to prosperity and success. The Group has embraced the State IRWMP process and its components as a potential tool to fully evaluate Valley water needs and alternatives and recommends adapting it as needed to best serve the Valley. Many IRWMP efforts have already begun but the meshing of the efforts into the inter-regional plans will take considerable encouragement and coordination. The Work Group is interested in an evaluation process that helps organize the water management planning efforts. Without a proper needs assessment, water budget and solutions that start with self-sufficiency, the State and the nation will be hard pressed to provide support and resources to any proposed physical (construction) solutions. The Water Work Group recommended the Partnership invite all parties who are part of the water environment to become part of the process at every level: regional, inter-regional, basin and Valley-wide.

REFERENCES

California Partnership for the San Joaquin Valley – Strategic Action Proposal, 2006

California Water Plan –, California Department of Water Resources, 2005 and 2009 (draft) updates

Page and Leblanc – U.S. Geological Survey, 1972, 1986

California Department of Finance – Population and Demographics, 2008

California Soil Resources Laboratory – UC Davis, 2008

Fresno, Madera, Merced, Kern, Kings, San Joaquin, Stanislaus, Tulare Agricultural Commissioners' Crop Reports for 2007

County of Fresno, COG Blueprint – 2008 (Draft)

California Legislative Analyst's Office – Report on Water Issues, October 2008

Tulare Basin Wildlife Partners Wetland and Riparian Corridor Plan – February 2009

FORECAST-COORDINATED OPERATIONS (F-CO) AND FORECAST- BASED OPERATIONS OF RESERVOIRS IN THE CENTRAL VALLEY, CALIFORNIA

Naser J. Bateni, P.E.[1]
Matt Zidar[2]

ABSTRACT

Communities in California's Central Valley, including both the Sacramento and San Joaquin Basins, are subject to flooding from rain and snowmelt flood events. This paper describes the Forecast-Coordinated Operations (F-CO) program being implemented by the California Department of Water Resources as part of the Flood Emergency Response component of the larger FloodSAFE program. It describes the program origin; purpose and need; goals, objectives, and benefits; and the tools and technology that have been developed and deployed. The F-CO program was developed and tested on the Yuba and Feather River system in partnership with the Yuba County Water Agency, U.S. Army Corps of Engineers (USACE), National Weather Service-River Forecast Center, the State Water Project, and Federal-State Flood Operation Center. Rainfall events trigger the largest threat on this system. A prototype F-CO Decision Support System was developed and deployed to support the exchange of data and information in near real-time between forecasters, reservoir operators, and the USACE. The F-CO will help reservoir operators to better protect downstream communities and farmland from flooding by coordinating reservoir releases, providing accurate and timely forecasts to meet flood control and water supply objectives, and improving downstream notifications. The F-CO partnership is to be implemented throughout the Central Valley starting with the San Joaquin watershed where in addition to rainfall, snowmelt events have potential impacts to downstream communities and present unique challenges to the operators of multi-purpose reservoirs. The paper ends with a conceptual description of efforts planned to expand this program throughout the Central Valley.

INTRODUCTION AND BACKGROUND OF THE F-CO

Pilot Program on the Yuba Feather System

Yuba County has a long history of catastrophic floods involving both the Yuba and Feather Rivers. After the 1997 major flood, with support from California Department of Water Resources (DWR), the Yuba County Water Agency (YCWA) conducted an investigation that resulted in detailed evaluation of requirements to increase the level of flood protection for the entire county (YCWA, 1998, 2001). The resulting "Feasibility Study for Yuba-Feather Supplemental Flood Control Project" identified six specific flood control improvement measures. One of the most cost-effective measures was determined to be the Yuba-Feather Forecast-Coordinated Operations of Lake Oroville (operated by

[1] Senior Vice President; GEI Consultants Inc., and Program Manager for Yuba-Feather F-CO Program; GEI, 10860 Gold Center Drive, Suite 350, Rancho Cordova, CA 95670; nbateni@geiconsultants.com
[2] Principal Hydrologist; GEI Consultants Inc., 10860 Gold Center Drive, Suite 350, Rancho Cordova, CA 95670; mzidar@geiconsultants.com

the State Water Project (SWP)) and New Bullards Bar Reservoir (owned and operated by YCWA). Through coordinated flood releases from the reservoirs; enhanced communication between local, State, and federal agencies; improved data gathering and exchange; and utilization of the most recent advancements to weather and river forecasting, the Yuba-Feather F-CO was designed to help minimize the risk of exceeding river channel capacity and increase the warning times to the communities along the Yuba and Feather Rivers and downstream. This multi-agency effort serves as the basis for inclusion of the F-CO program concepts into the broader efforts to resolve flood issues in the Central Valley of California.

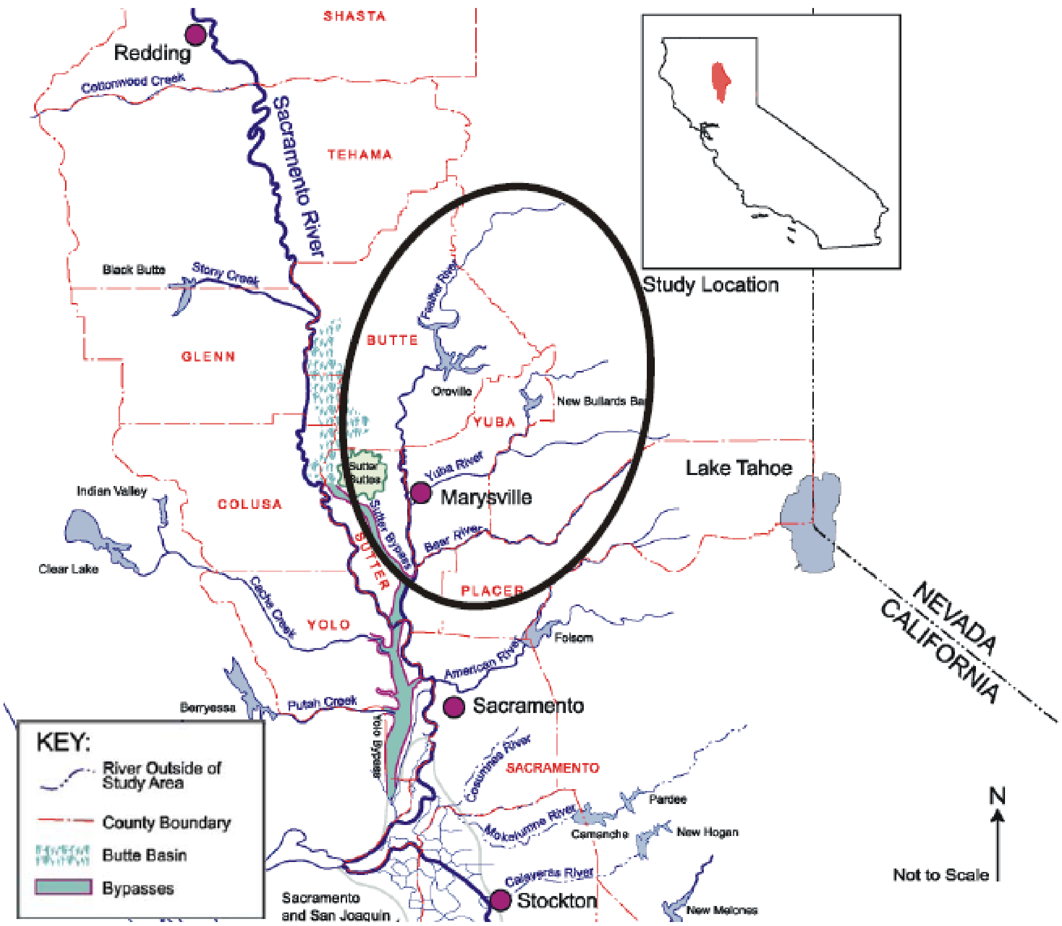


Figure 1. Yuba Feather River System

FloodSAFE and Flood ER

The record floods of 1997 and more recent floods of 2006 demonstrated the need to improve flood management facilities and emergency response operations in the Central Valley and throughout California. With this backdrop, in 2006 the California voters supported Propositions 1E and 84, providing bond funding to meet California’s flood management needs.

State government is taking aggressive steps to make flood system improvements to better protect communities from the ravages of flooding. The DWR has launched FloodSAFE California – a comprehensive program to improve public safety through implementation of integrated flood management. The Flood Emergency Response Program (Flood ER) is part of FloodSAFE California.

Flood ER includes all efforts for flood preparedness, response, and recovery. There are a number of individual projects within the Flood ER Program. The expansion of Forecast-Coordinated Operations from a pilot project to operational program for the Central Valley streams is one of the Flood ER initiatives.

The agencies involved in Yuba-Feather F-CO pilot project and their respective responsibilities were:

- DWR SWP Operations Control Office: operates Oroville Dam
- YCWA: operates New Bullards Bar Dam
- National Weather Service-River Forecast Center (NWS-CNRFC): forecasts reservoir inflow, local stream flows, and river forecasts
- DWR Division of Flood Management (DFM): works cooperatively with the NWS in forecasting, collects and manages data, and operates the Federal-State Flood Operation Center (FOC)
- DWR California Data Exchange Center (CDEC): maintains central F-CO Decision Support System (DSS) data and modeling infrastructures
- U.S. Army Corps of Engineers: has authority over the management of flood control pools of the reservoirs with flood control reservations. In addition, the USACE Hydrologic Engineering Center (HEC) maintains and updates HEC models, including HEC- ResSim, the tools used for reservoir operations modeling

During flood events, reservoir operators operate their reservoirs based on reservoir storage, forecasted inflow, and the operating rules set forth in the USACE Water Control Manual for their individual facilities. The Sacramento District of the USACE plays a key role in the management of flood pools in the Central Valley reservoir system and has been an important partner in the development of the F-CO program. The construction of many of the multi-purpose reservoirs relied on federal funds and in accordance with Section 7 of the Flood Control Act of 1944. These facilities are subject to rules prescribed in reservoir Water Control Manuals. The *flood control diagrams* specify how the reservoir flood pool is to be utilized and direct how releases can be made by the reservoir operators during flood operations; also defining the downstream *objective flows* above which damage may result. The USACE has regulatory authority that can authorize deviations from the Water Control Manual.

THE F-CO PURPOSE AND NEED

Rainfall and snowmelt events can cause substantial flooding and enormous economic impacts to communities of the Central Valley. Upstream reservoirs have been designed and built to meet multiple purposes, including water supply, recreation, and flood control.

Most multi-purpose reservoirs have defined water conservation pools for capturing winter runoff for water supply purposes, and designated flood control pools to capture and manage these flood waters to reduce downstream impacts.

The F-CO seeks to improve management of the flood control pools to reduce peak flood flows downstream through use of improved forecasting and coordination during flood operations. Operators need forecasted reservoir inflows for both rain and snowmelt events; tools to analyze alternative reservoir release schedules; an ability to observe the downstream effects of their releases and of the releases of other operators within the river system; and capabilities to share the data and communicate when making flood operations decisions. Coordinated operation of reservoirs in the Central Valley river systems is best accomplished when weather, water, and management information are shared and when operational decisions are coordinated among the agencies involved.

Need for Improved Flood Forecasting

Effective tools to forecast weather that is used to predict watershed runoff (rain, snowmelt) and to model reservoir operations during flooding are essential elements of the flood operation. Improvement of these tools will improve flood forecasting, increase the flood warning lead time, and expedite the response to high water conditions, reduce flood damage, and protect lives.

The primary challenge to flood managers at the DWR and CNRFC is to have adequate real-time rainfall, snowmelt, and stream flow data; accurate tools and technologies with which to forecast weather and reservoir inflows; and the capability to rapidly exchange and share information among river forecasters, FOC, reservoir operators, and emergency response agencies.

The reservoir inflow forecasts are based on complex weather models, real-time data networks, and watershed rainfall/snowmelt runoff models. During flood events, reservoir operators rely on inflow forecasts. California, through CDEC and the CNFRC, has one of the most well regarded flood forecasting and real-time flood warning systems in the world. Even with these capabilities, the forecasting technology and tools used for operating reservoirs during floods are evolving, and this presents an opportunity for enhancement of flood forecasts.

In the past, forecasts of reservoir inflows were provided by DWR and CNRFC and used by reservoir operators to make release decisions. The release schedules were not always provided to the DWR or CNRFC in a timely manner so that they could be factored into the forecast of stream flows below the reservoir. Forecasters did not always have accurate information on reservoir releases, resulting in reduced accuracy of the downstream forecasted flows. Technology and tools were needed to close this feedback loop and allow forecasters to provide timely reservoir inflow forecasts to operators, allow operators to provide release schedules back to the forecasters, and for forecasters to provide better downstream flow estimates for decision makers and downstream emergency responders.

Improving Flood Operation Coordination

Although technology continues to improve forecasts and facilitates exchange of data and reservoir operation analysis results, coordination and communication remains a human endeavor; influenced by both institutional roles and individual relationships.

The F-CO seeks to help reservoir operators meet individual objectives while at the same time support joint coordinated release and operational decisions to make best use of available flood storage space throughout the system. The management process and partnerships formed during development of the F-CO contributed significantly to enhanced coordinated approach to reservoir operations during the flooding.

Local operators are constantly striving to meet the multiple objectives of water supply and flood control, and these objectives can sometimes be in conflict. During flood events in the Sacramento and San Joaquin valleys, one of the primary challenges to operating reservoirs is that decisions about system operation are made by several State and local operators, with input and guidance from federal agencies; and these decisions depend on operators having access to accurate and timely information and the ability to exchange information in near real-time under stressful conditions. Common awareness and understanding of the roles and responsibilities, operational constraints and opportunities, standard protocols, and accurate information are needed to coordinate. During flood events, the DWR uses CDEC to share information. DWR also mobilizes the Flood Operations Center during flood conditions. Under the F-CO Program the FOC serves to facilitate communications between the forecasters, reservoir operators, and the U.S. Army Corps of Engineers on coordinated reservoir releases. Protocols are also developed to provide a framework for the coordinated operations.

F-CO GOALS AND OBJECTIVES

The overall goal of the F-CO program is to provide better runoff forecasts to individual reservoir operators and improve coordination between reservoir operators, regulators and flood emergency responders within the Sacramento and San Joaquin watersheds so that system-wide effects are considered when making reservoir release decisions. This will reduce peak flows and minimize the chances of downstream flooding over the duration of the flood event. Specific Sacramento and/or San Joaquin watersheds' F-CO program objectives will be established through coordination and discussion with local reservoir operators. The objectives will be met through a multi-agency effort of local reservoir operators, DWR, NWS-CNRFC, and USACE.

Forecast-Coordinated Operations formalizes the mechanism for exchange of information (hydrologic forecasts, as well as weather data and operation information) among the cooperating agencies. F-CO calls for sharing information regarding likely future releases so that system-wide operation can be coordinated and optimized. With F-CO, forecasters provide estimates of inflow into the reservoirs and, in turn, reservoir operators provide anticipated releases based on these flows.

F-CO BENEFITS TO LOCAL RESERVOIR OPERATORS

Just as air traffic controllers work with pilots to manage congested airways, the coordinated operations of reservoirs helps reservoir operators to manage peak flows in congested rivers downstream of the reservoirs during storms. This reduces the chance of levee breaks or exceeding downstream channel capacity. Coordinated operations can also improve notification processes and provide better river stage forecast data to downstream emergency operation managers, levee districts, and State and local Offices of Emergency Services.

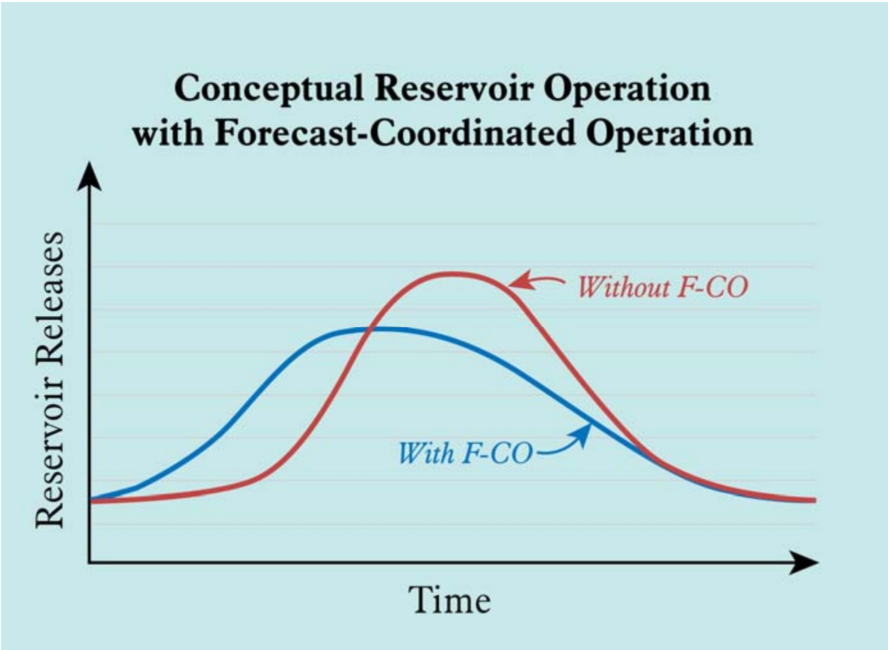


Figure 2. Reservoir Releases

The F-CO is also expected to improve the ability to meet reservoir operating requirements through close coordination with the FOC and the USACE during major flood events, thus reducing local agencies' flood damage liabilities. In addition, the program provides the opportunity for local agencies to work closely with USACE to modify, clarify, or change flood control diagrams, if needed, to enhance water operations. The additional capabilities provided through the F-CO program also offer local operators the opportunity to provide better flood protection for downstream communities, improving community relationships without any water supply impacts.

F-CO DEVELOPMENT AND IMPLEMENTATION

F-CO Program Management

The Yuba-Feather F-CO development served as a pilot project that would be expanded to other watersheds in the Central Valley. Lessons learned through development of the

Yuba-Feather F-CO will be used in development of the F-CO for other reservoirs in the Central Valley.

During the development of the Yuba-Feather Rivers F-CO, a Management Team was formed by the partners and met monthly to provide direction to the F-CO Development Team, resolve management issues, coordinate efforts, and make critical decisions for program development. The Management Team helped to facilitate agreements between the agencies, review and define operational protocols, and to develop relationships between key agencies' staff. It served to build trust, create a common understanding, and to build relationships during the development effort that would carry over into the operational environment during flood times.

Ad hoc work groups were formed to efficiently address specific technical issues as they arose. The work groups evaluated alternatives and provided solutions and recommendations to the Management Team for decision. An interagency agreement was developed to guide the F-CO operation and define how resources would be allocated. The effort resulted in some unique collaborations and coordination among all participating agencies.

For the broader effort to implement the F-CO in the Central Valley, DWR plans to utilize a similar program management approach.

Development of tools for F-CO

The Yuba-Feather Rivers F-CO included the development of the F-CO Decision Support System (DSS), which is deployed in a distributed manner. The F-CO DSS can be accessed and used from remote locations by authorized personnel via the Internet. With the implementation of this F-CO DSS, the YCWA, DWR, and the USACE are able to exchange information efficiently. The expertise and input of the agencies and consulting team has helped the F-CO program achieve the objectives and deliver the expected benefits. The experience, information, and accomplishments of the program will be used for coordinated operations of other reservoirs in the Central Valley.

The primary purpose of the DSS is to provide tools for effective coordination of the reservoir operations. The agencies involved in the development of the Yuba-Feather prototype identified several performance and structural requirements as listed below. The DSS was designed to:

- Allow the agencies involved to rely on a centrally located database that supports the sharing of reservoir operations models and modeling results.
- Be redundant, ensuring that if one component of the DSS fails, the system can still complete mission-critical tasks.
- Be sufficiently flexible to accommodate changes to system operation and features.
- Be readily usable by reservoir operators.
- Provide sufficient information to answer questions likely to be asked during coordinated operation decision-making.

- Include a powerful reservoir simulation component capable of representing the reservoirs and the river system.
- Provide secure user access and protect sensitive information, including hydropower releases planned by utilities.
- Provide convenient remote access under normal operations and during flood emergencies.
- Consolidate the IT management, minimizing the needs for unnecessary hardware, software and support staff at the local operating agencies.
- Archive files, so that users can go back after major events to test the system and re-create the events for training purposes.

Reservoir Simulation Model and the User Interface

At the heart of the DSS is the ResSim Model developed and enhanced by the HEC. The ResSim model:

- Simulates operation of the individual reservoirs, and all reservoirs within the river system.
- Simulates downstream river system operation using the reservoir operation outputs of all reservoirs on the system.
- Is effectively integrated with NWS River Forecasting System.
- Includes a reservoir flood release selection algorithm that is flexible so that it can be modified to incorporate knowledge gained by operators as well as selecting release rate that would provide for coordinated operations with other reservoirs within the system.
- Uses an analysis time step appropriate for flood operations.
- Allows user override of releases determined with strict interpretation of operation rules.
- Permits parallel reservoir operation of all reservoirs in the system over the forecast period using operator specified releases.
- Includes capability to evaluate the impact of various spillway gate operations, including operations in which selected gates or outlet features are not available for operation.
- Is capable of incorporating forecast probability range using ensemble forecasts.
- Is fully integrated with a central database located at the CDEC.
- Functions in both a stand-alone planning mode and a real-time operation mode.

A user-friendly interface has been developed for the ResSim model. The user interface is available to all participating agencies. Through the interface the reservoir operators, FOC, USACE, and the NWS-RFC staff can easily run the ResSim and together see the results of model operations downstream and to coordinate their decision-making.

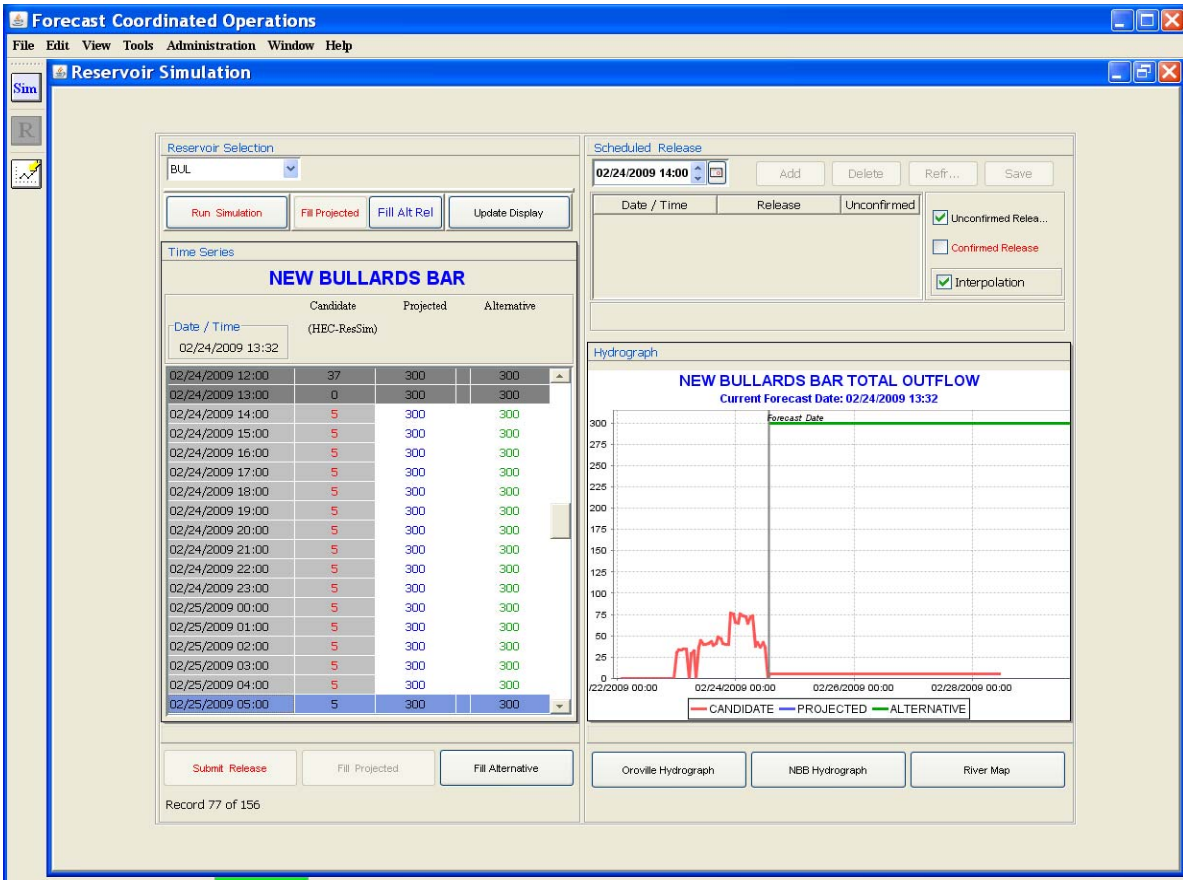


Figure 3. ResSim User Interface

Use of F-CO

Using the F-CO DSS components and coordination protocols developed for the Yuba-Feather River system, the cooperating agencies conducted flood emergency exercises in 2008 and 2009. Positive user feedback and opportunities for further development were received in both exercises. It is the intention to make use of the systems during the 2009/2010 flood season to support coordinated operations. The following program tasks have been accomplished as part of the Yuba-Feather F-CO DSS development:

- Identified needs and purchased, installed, and tested information systems platforms; including hardware, software, and specific applications that improve communications, access to information, reservoir modeling, and forecasting of river flows.
- Identified data needs and purchased, installed, and tested state-of-the-art gaging stations that provide high quality, real-time data for multiple purposes and programs.
- Developed and tested communications protocols and software for data transfers between reservoir operators and the FOC.
- Designed, coded, and tested the enhanced ResSim reservoir model to provide capabilities to test a range of operating conditions and to accurately simulate

downstream flows at specific control point locations with defined flow requirements.

- Designed and developed an easy-to-use Internet based, web-enabled graphical user interface for reservoir operators to access the enhanced ResSim, to run real-time reservoir operations scenarios and to exchange information with the FOC.
- Coordinated operational procedures for New Bullard Bar Reservoir (YCWA) and Lake Oroville (DWR) during major floods using the technical tools, data, and modeling.
- Conducted of pre-season flood coordination meetings and functional exercises between DWR SWP, YCWA, NWS-RFC, DWR Flood Management, and USACE.
- Design of tools for training and planning purposes that help operators gain experience over a wide range of potential flood operation events.

The user interface provides the basis for expansion of the program. Additional functionalities and capabilities needed to support the unique conditions on the Sacramento and San Joaquin Rivers are to be determined in cooperation with local reservoir operators. Further work is planned to integrate ensemble forecasts into the DSS and to integrate ensemble capabilities into ResSim. This will allow for evaluating and factoring forecasting uncertainties into the decision-making process.

F-CO Architecture and Coordinated Protocol

The DSS would enable local operators, DWR, CNRFC, and the USACE to exchange information efficiently in support of F-CO of the Central Valley River systems and to coordinate the reservoir operations throughout the system. Local operators could also use tools developed for their individual systems and may be able to have these integrated into local system. The F-CO DSS is deployed in a distributed manner, with hardware and software housed at CDEC. An integrated information system has been developed and installed in support of the F-CO.

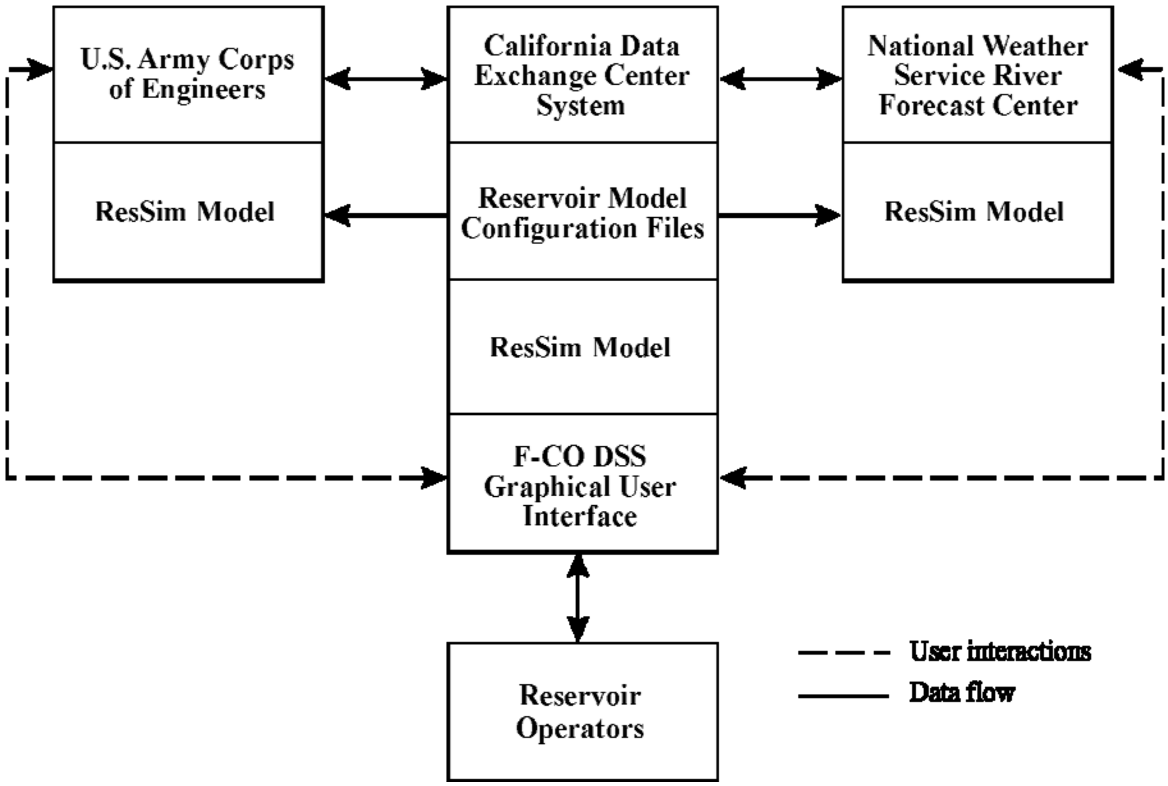


Figure 4. F-CO Conceptual Decision Support System Schematic

The forecast of inflow to reservoirs relies on data retrieved from the CDEC database. The forecast is also stored in the CDEC database. The initial inflow and local flow forecast (watershed runoff forecast) are retrieved from the CDEC database by the operator. Using the watershed forecast, the HEC-ResSim program (reside at CDEC and at NWS-CNRFC) is executed to produce an initial release forecast. That release forecast is posted to the CDEC system for reservoir operator review and evaluation.

The NWSRFS inflow and local flow forecast and the initial release forecast from HEC-ResSim would be made available through the F-CO interface to the local operators on the Sacramento or San Joaquin river systems.

The operators can override and alter the release forecast through the F-CO interface. If they alter the release forecast, the F-CO server transmits the new values back to the CDEC database where they are stored temporarily in a secure area. During major flood events, the final decision on releases from any reservoir in the system would be coordinated with other reservoir operators, FOC, and with USACE. Then the final (coordinated) release forecast is retrieved and analyzed with HEC-ResSim, thus providing to the operators and USACE a system-wide assessment of the impacts of changes that they propose. Once operators and USACE are satisfied that they have selected the best releases, through the above coordinated operations, they post their release schedule to the CDEC database, with information flowing from the operators to the CDEC database and finally to NWS-RFC. With the final reservoir release schedule, routings are completed, and NWS and DWR forecasters complete the final system-wide river forecasts and notifications. This system-wide forecast is posted again to the CDEC database, where it is available for public access.

GENERAL APPROACH TO FURTHER DEVELOPMENT OF THE F-CO

In rolling out the F-CO concept to the rest of the Central Valley, DWR anticipates a two-phase effort:

- Phase 1 – Planning and Design
- Phase 2 – Implementation

In Phase 1, the issues, constraints, and opportunities for improved operations of major reservoirs will be assessed; outreach efforts to local agencies will be conducted; current tools and technologies used in forecasting inflows and reservoir operations will be identified; operational and downstream constraints will be evaluated; opportunities to optimize operations will be identified; and operational protocols and program implementation plans for each watershed will be developed. The local operators will participate in further development of the F-CO and a decision support system that would reflect the participating agencies' needs. The local operators would also participate in an F-CO Management Team comprised of representatives of the cooperating agencies to formulate and lead the development of the F-CO for their watershed.

DWR is working to develop agreements with the local operators in the San Joaquin to implement the overall F-CO program, join the management team, and to support further development and deployment of the F-CO DSS for the San Joaquin.

During Phase 2 the program elements as defined in Phase 1 will be implemented. This may include the installation of additional gaging systems; development of additional watershed forecasting and reservoir operations models; enhancement of the Decision Support Systems; clarification of operating rules; and conducting training and flood exercises. The outcome of implementation will include:

- Five-day reservoir release schedules - reservoir operators will have an enhanced five-day reservoir inflow forecast with an improved reservoir operation model so they can provide a five-day release schedule to river forecasters and the FOC.
- Enhanced reservoir operations using improved Quantitative Precipitation Forecasts (QPF) and improved watershed seasonal runoff forecasting.
- Coordinated operations of the reservoirs to reduce peak flood flows downstream.
- Necessary clarification of the Water Control Manuals to implement this phase of the program.

Forecast-Based Operations

During the flood season, reservoir operators currently (and under F-CO) follow the Water Control Manuals and corresponding flood control diagrams developed by USACE for operations of the reservoir flood pool. Most of the flood control diagrams do not provide the operational flexibility needed to improve flood protection or water supply. Under these flood control diagrams reservoir operation cannot be adapted to change in watershed hydrology or to climate change. The purpose of the Forecast-Based Operations (FBO) is to provide operational flexibility based on changing watershed parameters. These parameters may include seasonal variation in watershed conditions such as snow accumulations in the basin, basin wetness, near term runoff forecasts, and an improved QPF for the watershed; or could be long-term change in conditions such as watershed runoff patterns and climate change. To implement F-BO, an improved longer-term watershed runoff forecast (current F-BO program objective is a five-day advance forecast) with probability range and enhanced QPF will be needed. Improved runoff forecasting will also require employing ensembles in forecasting that could provide a probability range for the forecasted flows. Reservoir operators can then use the five-day forecast with probability range to make sound decisions, in advance of the storms, to operate their reservoirs. F-BO is considered to be an advance step in reservoir operations and naturally the next step in development and implementation of the F-CO.

It is anticipated that climate change may necessitate the use of Forecast-Based Operations in the future in many Sierra Nevada Watersheds. As watershed hydrology changes due to the climate change the existing flood control diagrams may no longer be appropriate. Climate change may have significant impact on snow coverage as well as snowmelt season. In the future, effective operation of the flood pool and the conservation pool will likely require changes in reservoir operations and corresponding flood control diagrams. DWR is currently updating the hydrology of Central Valley streams and will be analyzing climate change. The updated hydrology and climate change analyses will help define impacts to reservoir operations and the need to modify any particular reservoir's flood control diagram. Such modifications in flood control manuals and corresponding diagrams would likely require environmental review and could require additional Congressional authorizations.

REFERENCES

David Ford Consulting Engineers, Inc., 2009. Oroville-New Bullards Bar Forecast-Coordinated Operations: Decision Support System Technical Documentation. November 2009.

YCWA, GEI Consultants Inc. 1998. Program Definition for Supplemental Flood Control on the Yuba River. March 1998.

YCWA, GEI Consultants Inc. 2001. Formulation and Analysis of Alternatives for Supplemental Flood Control Program on the Yuba River.

INTEGRATED REGIONAL WATER MANAGEMENT IN CALIFORNIA

Eric Hong, P.E[1]

ABSTRACT

Integrated Regional Water Management (IRWM) is the application of broader Integrated Water Management principles on a regional basis. Integrated Water Management is a philosophy and process of coordinating the management of water, land and related resources, with the goal of maximizing economic and social welfare while maintaining the ecosystem sustainability. In practice, Integrated Water Management involves coordinating laws, policies, and investment decisions that affect the development and management of water supplies, water demand, water quality, flood management, and environmental protection and enhancement to meet defined objectives.

The California Water Plan identifies two key initiatives for advancing management of California's water resources:

- Promote, improve, and expand Integrated Regional Water Management to enable regions to implement strategies appropriate for their own needs and help them become more self-sufficient.

- Improve statewide water management systems to provide for upgrades to the large physical facilities, such as the State Water Project, and statewide management programs essential to the California economy.

It should be noted that although issues concerning statewide water management systems often receive the most attention (e.g., management of the State Water Project and Central Valley Project in light of drought, climate change and the decline of the Sacramento – San Joaquin Delta), the majority of California's water management investments are made at the local and regional levels. As such, Integrated Water Management principles should apply to both regional water management and the management of statewide water systems.

As changes are considered to how California's water resources are governed, application of the Integrated Water Management philosophy and its principles should be at the forefront.

CONCEPT OF INTEGRATED REGIONAL WATER MANAGEMENT

IRWM is a collaborative effort to manage all aspects of water resources, integrate local agency responses to resource management issues and facilitate compliance with State laws and policies on a regional level. It is a comprehensive approach for determining the appropriate mix of water demand and supply management options and water quality

[1] Chief, Regional Partnership Section, Division of Integrated Regional Water Management, California Department of Water Resources, PO Box 942836, Sacramento, CA 94236-0001; ehong@water.ca.gov

actions to provide long-term, reliable water supplies for all uses at the lowest reasonable cost and with the highest possible benefits for providing economic development, environmental quality, and meeting other societal objectives.

Over the past decade, California has furthered its understanding of the value of regional planning and made significant steps in implementing IRWM. IRWM plans are developed on a regional basis, considering watershed, jurisdictional and political boundaries; involve multiple agencies, stakeholders, individuals, and groups; and attempt to address the issues and differing perspectives of all the entities involved through mutually beneficial solutions.

IRWM actions provide multiple benefits, including meeting existing and future water demands; improving the quality of water sources and supplies; providing flexibility to deal with extreme hydrological events, such as droughts, climate change, and floods; and restoring and enhancing ecosystems to help sustain our natural resources.

DEVELOPMENT OF INTEGRATED REGIONAL WATER MANAGEMENT IN CALIFORNIA

IRWM is an example of integrated resource planning, which began in the late 1980s in the electric power industry as a comprehensive approach to resource management and planning. When applied to water management, integrated resource planning is a systems approach that balances relationships between different aspects of water resource management to meet defined objectives, with an understanding that changes in the management of one aspect of water resources can affect others. Because water resources are often not confined to the boundaries of a single water management agency, a consensus-based, cross-jurisdictional, regional approach provides an opportunity to formulate comprehensive solutions to water resource issues within a region. The tools to formulate these solutions include a broad range of water resource management strategies which relate to water supply, water quality, water use efficiency, operational flexibility, flood management and environmental stewardship.

In the past, water management entities tended to work with a focus on their service area and primary function, at times competing against similar efforts by others to resolve similar issues or advance duplicative efforts. IRWM operates on the principle that each stakeholder holds a piece of the water management solution for their region and that the best solutions require better communication, collaboration and understanding of regional issues than has previously occurred.

To encourage local agencies to work cooperatively to manage local and imported water supplies for improving the quality, quantity, and reliability of those supplies, the Integrated Regional Water Management Act of 2002 (SB 1672, Costa) added §10530 to the California Water Code. However, while this Act provided the authority for IRWM plans, it provided little guidance or incentive for IRWM planning or implementation.
In September 2008, the Integrated Regional Water Management Planning Act was amended by the legislature and signed by the Governor. The IRWM Act amended the

California Water Code and provided an updated general definition of an IRWM plan as well as guidance to State agencies as to what IRWM program guidelines must contain.

Over the past decade, IRWM efforts have emerged across California as a result of some local governments and agencies looking for alternatives to contentious, protracted law suits and others responding to financial incentives offered by the State. A derived benefit has been that many local governments and agencies are now working more closely on a regional basis and better integrating their resource management decisions. This typically results in more efficient and sustainable water management plans and better representation and transparency in water management decisions for the region.

OPPORTUNITIES FOR COORDINATING STATE LAWS AND POLICY

IRWM can also serve as a framework for providing better coordination of State laws and policies. As State agencies with water management authority and responsibility work together to develop and refine IRWM guidelines and review IRWM plans, in doing so, they must jointly consider potential conflicts and develop priorities in implementing those laws and policies. State agencies are motivated to work collaboratively on IRWM guidelines, because access to State funding can provide a strong incentive for local agencies to comply with State laws and policies. Additionally, issuing State financial assistance through a coordinated IRWM program -- as opposed to many single purpose grant programs -- provides a single point of coordination for both local and state agencies and allows flexibility in using and leveraging available funding for the highest regional priorities.

IRWM encourages local governments and agencies to work together on a regional basis to define water resources management objectives and priorities; integrate infrastructure and other assets to improve efficiency of investments; develop a diverse portfolio of water management programs, projects and management tools to improve water supply reliability and sustainability; and improve the involvement and collaboration of diverse interest groups and stakeholders. To further the IRWM program, State agencies should leverage this regional coordination and collaboration by working together to develop and refine guidelines that set minimum requirements and competitive criteria for IRWM plans. State IRWM guidelines should seek to integrate all applicable State laws and policies, both to provide a single point of information for local governments and agencies and to focus State financial incentives on compliance with those laws and policies.

Options should be explored for leveraging available State agency funding, such as integrating more State financial assistance programs with the IRWM process. This could take the form of moving more State funding from single purpose grant and loan programs into the IRWM fund or requiring local proposals for State funding from those single purpose grant funds to be consistent with an adopted and approved IRWM plan.

This approach can improve the functionality of the existing State governance structure; however, a key to success is that all applicable State agencies must have the necessary staff resources to participate in the collaborative process. In addition, staff resources are required to further the effectiveness of IRWM by developing and refining IRWM guidelines and evaluating IRWM plans and implementation efforts. As State budgets become leaner, coordination efforts must often be sacrificed in favor of complying with the core mission of any given agency, or even the core mission of individual programs within agencies.

INCENTIVES TO ADVANCE REGIONAL PARTICIPATION IN IRWM

Throughout California most regions are engaged in IRWM planning and the California Department of Water Resources (DWR) is encouraged by the level of interest and response to the IRWM program. To continue to advance regional participation in IRWM, DWR should:

- Continue to work with other State agencies and encourage their participation in developing IRWM guidelines and reviewing IRWM plans. Broader incorporation of State laws and policies will provide additional incentive for regional participation.

- As funds are available, provide financial assistance to local agencies to improve their plans and, particularly in economically disadvantaged areas, provide capacity to engage in the planning process. Provide facilitation services to local agencies when requested.

- Attempt to clarify minimum levels of outreach and participation in IRWM plans. Because all regions are unique, this is best accomplished by State agency staff being available for at least a minimum level of observation and participation in regional planning processes to assure adequate collaboration of regional interests is occurring.

- Provide clear, consistent guidelines for regional development of IRWM plans and State agency review of those plans. Requirements for IRWM plans must evolve over time, but changes to guidelines must only be made after deliberative, transparent public processes. State agencies must provide sufficient lead time and possible cost sharing for making improvements to IRWM plans necessary to meet the new guidelines.

- Provide adequate and consistent incentive through IRWM implementation grants. Funding cycles must occur often enough to maintain momentum of regional planning processes. Over the long term, identifying a consistent source of funding for IRWM grants to replace general obligation bond funding will likely be necessary.

FINANCIAL INCENTIVES FOR IRWM

With the passage of a number of water bonds over the last decade, we have learned that bond funds can provide significant leverage for investment of local funds resulting in major investments in the State's water infrastructure and programs.

In November 2002, California voters passed Proposition 50, the *Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002*, which provided $500 million to fund competitive grants for projects consistent with an adopted IRWM plan. The grant program was conducted as a joint effort between DWR and the State Water Quality Control Board to provide both planning and implementation grants to IRWM efforts. The incentive provided by this funding, as well as the direction provided in grant program guidelines, were major drivers in IRWM.

In November 2006, California voters passed Proposition 84, the *Safe Drinking Water, Water Quality, and Supply, Flood Control, River and Coastal Protection Bond Act of 2006*. Proposition 84 provides $1 billion for IRWM planning and implementation. At the same time, California voters also passed Proposition 1E, the *Disaster Preparedness and Flood Prevention Bond Act of 2006,* which provides, among other actions, $300,000,000 for storm water projects that reduce flood damage and are consistent with an IRWM plan.

A proposed new water bond, the *Safe, Clean, and Reliable Drinking Water Supply Act of 2010*, will go to California voters in November 2010. Passage of this new bond measure would provide an additional $1.4 billion to support the existing IRWM program.

Past experience indicates that an investment of $1 billion in IRWM from State bond funds could result in water supply benefits of approximately 1.2 million acre-feet per year in addition to a number of ancillary benefits to water quality, the environment, flood protection and other regional objectives.

INCORPORATING STATE POLICIES IN IRWM PLAN GUIDELINES AND REQUIREMENTS

As noted in the California Water Plan Update 2005, IRWM is one of the initiatives key to ensuring reliable water supplies in the future. IRWM will help communities and regions incorporate sustainable actions into their water management efforts. A main focus of IRWM planning is diversification of a region's water portfolio so that multiple resource management strategies are employed in meeting future water and water quality needs of all sectors. This diversification should help regions to better prepare to face an uncertain future of water availability and water use; while protecting and improving water quality and the environment.

The next update of the California Water Plan, to be finalized early in 2010, presents over 25 resource management strategies that should be considered in developing IRWM plans. DWR has worked with more than 15 State agencies through a steering committee effort, and employed a robust public involvement program to develop the California Water Plan update.

DWR has implemented a Regional Acceptance Process (RAP) to determine eligible entities for competing for the first round of IRWM grants made available from Proposition 84 funding. Since the inception of the IRWM program, DWR has encouraged and supported the formation of self-determined IRWM regions, encouraging broader, watershed-based planning areas whenever possible. DWR acknowledges multiple perspectives on water management issues and requires collaborative involvement of multiple stakeholders as a basic eligibility requirement for an IRWM region.

In the first RAP cycle, DWR received 46 proposals for IRWM regions. These regions cover 82 percent of the State lands and 98 percent of the State population. In the final RAP determination thirty-five regions were approved and eleven regions received conditional approval (Figure 1). If State economic conditions allow adequate access to General Obligation bond funding, DWR will proceed with the first cycle of Proposition 84 competitive IRWM grant funding in the coming months.

CONCLUSION

As a key initiative of the California Water Plan, IRWM is a long term approach to water management in California. With IRWM, regions have been able to take advantage of opportunities that are not always available to individual water suppliers; reduce dependence on imported water and make better use of local supplies; enhance use of groundwater with greater ability to limit groundwater overdraft; increase supply reliability and security; and improve water quality.

IRWM is a process that evaluates water resources management over an entire watershed or region, determines current and future water demands for many diverse uses, and then produces a comprehensive, adaptive plan for sustainable water uses in the region. As IRWM continues to evolve, DWR seeks to encourage planning efforts that are that are collaborative and use broad stakeholder participation and involvement that leads to diversity of water management strategies. Such planning efforts can live well into the future beyond current state funding initiatives.

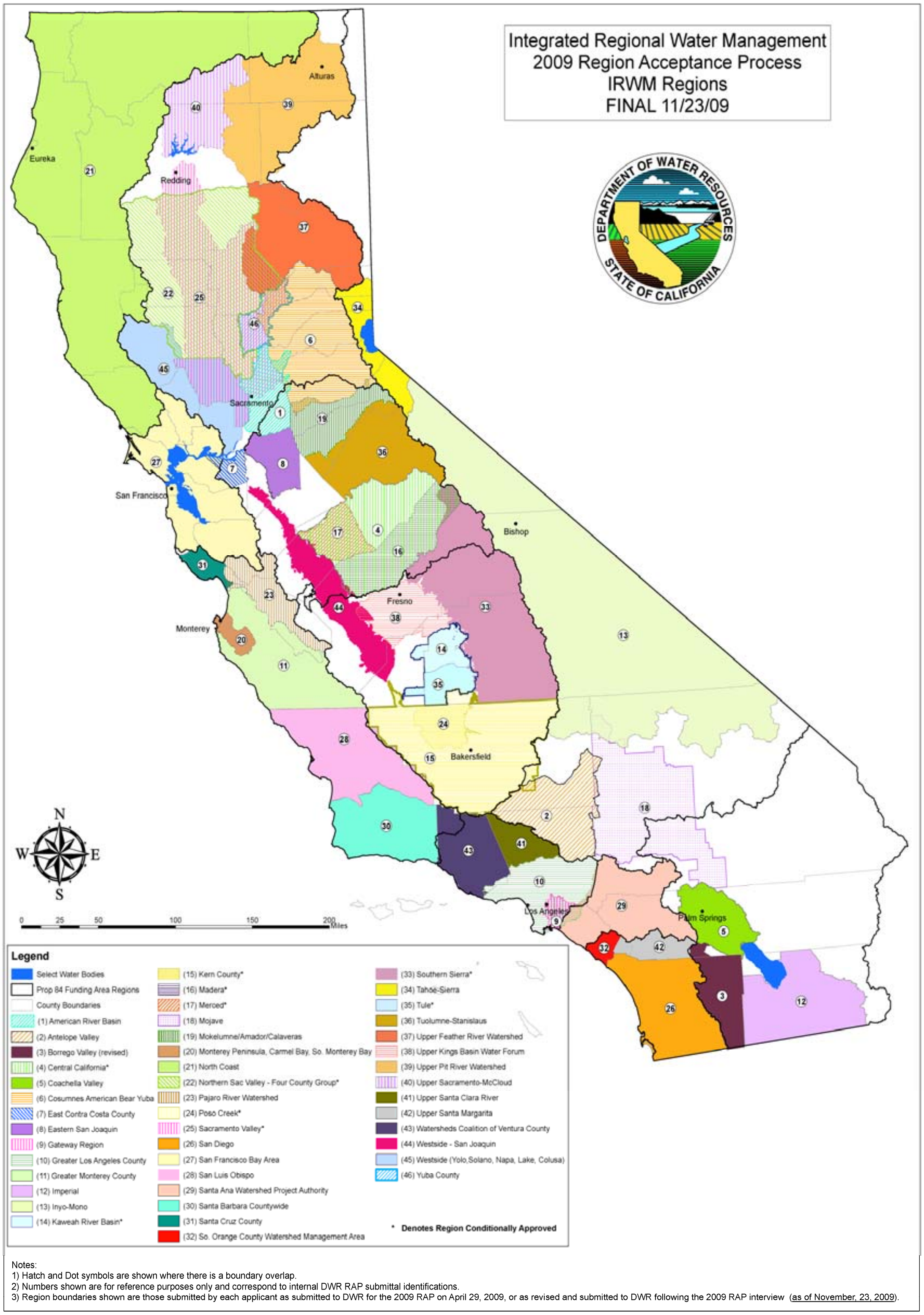


Figure 1. Final IRWM Region Acceptance Process Determinations

REFERENCES

California Department of Water Resources. 2005. California Water Plan Update 2005. Sacramento. Bulletin 160-05. 5 v.

California Department of Water Resources. 2009. California Water Plan Update 2009, Pre-Final Draft. Sacramento. Bulletin 160-09. 5 v.

Cowin, Mark (California Department of Water Resources). 2009. Little Hoover Commission Public Hearing on Water Governance. 7 p.

APPLICATION OF CONFLICT RESOLUTION IN INTEGRATED WATER RESOURCES MANAGMENT

E. Fallah-Mehdipour[1]
O. Bozorg Haddad[2]

ABSTRACT

Over the years, optimal management has been a goal of humans in all fields of life. Water resources management is a field of water engineering that involves different stakeholders with several groups and objectives. Reservoir operation is an example in water resources management in which decision making about its operation is very important.

Optimal operation of a single-reservoir system depends on inflow and storage volume, and operator or decision maker can decide about release volume in each period. But releases from upstream reservoirs are added to the aforementioned factors in optimal operation of a multi-reservoir system. Thus, an optimization model which is capable of considering all factors and finds an optimal solution is needed. In a multi-reservoir system each reservoir is following its utility, which causes extended conflicts. To overcome these conflicts, the Nash conflict resolution model is a suitable option. On the other hand, integrated water resources management (IWRM) approaches that attempt to improve water use efficiency, mitigate stakeholder conflicts, and evaluate the effects of different alternatives are needed.

In this paper, optimal operation of a three-reservoir system with supplying downstream demand objective has been considered. At the first step, two types of objective structures which are in the separated and integrated methods have been applied. In the second step, to overcome the existing conflicts among reservoirs' stakeholders, the Nash model has been used as the optimization model. Results of this model present the optimal solution in a decision space that can provide most of the utility for all of stakeholders at the same time.

INTRODUCTION

Limitation of different resources is one of the most important issues in human life. Water resources are as same as other resources, too. In conditions of limitation, optimum use of existing resources and facilities is a basic possible way. A water reservoir (dam) is a water structure that impounds a water stream. Generally, the first purpose of reservoir operation is retaining water, which can use to other fields such as supplying downstream

[1] Ph.D. Student, Department of Irrigation & Reclamation Engineering, Faculty of Soil & water Engineering, College of Agriculture & Natural Resources, University of Tehran, Karaj, Tehran, Iran. E-mail: Falah@ut.ac.ir
[2] Assistant Professor, Department of Irrigation & Reclamation Engineering, Faculty of Soil & water Engineering, College of Agriculture & Natural Resources, University of Tehran, Karaj, Tehran, Iran. E-mail: OBHaddad@ut.ac.ir

reservoir demands, generating hydropower energy, land reclamation, and others. Simulation models are capable to use linear and nonlinear relations in different conditions. But, finding the possible optimal solution is directly related to the number of trial-and-error iterations. Thus, an optimization method is commonly added to the simulation models.

Labadie (2004) reviewed optimal operation of multi-reservoir systems. The objective function and constraints were identified as the parts of a reservoir system optimization problem. He was convinced that the keys to success in implementation of reservoir system optimization models are: (1) improving the level of trust by more interactive involvement of decision makers in system development; (2) better "packaging" of these systems; and (3) improved linkage with simulation models which operators more readily accept (Labadie, 2004). On the other hand, water resource management projects in general, and reservoir system projects in particular, are involving group decisions making with different interests, utilities, or objectives. Cai et al. (2004) categorized characteristic and challenges in water management including: (1) multidisciplinary complexity; (2) domain-dependent knowledge; (3) social value orientation; (4) institutional constraints; and (5) cultural dimensions.

These topics cause some conflicts among different groups of decisions makers. In water resources management, integrated water resource management (IWRM) suggests some methods and techniques to reduce some conflicts and help increasing the system efficiency. Davis (2007) identified IWRM as an old concept that has proven difficult to implement. He showed the slow progress towards IWRM (as evidenced through historic water management based on sector focus, limited participation, and restricted criteria) often has resulted in suboptimal outcomes with certain sectors disenfranchised and other sectors adversely affected, sometime irreparably (Davis 2007). There are some conflict resolution models that can apply IWRM concepts and reduce existing conflicts. The Nash conflict resolution model is one of the mentioned models. Raquel et al. (2007) reviewed application of the Nash model for conflict resolution in the operation of groundwater in a region of Mexico. They proposed both economic and environmental aspects in a model as the two groups of conflicts. Ganji et al. (2007) applied a stochastic dynamic programming (SDP) based on the Nash model and used it in a single-reservoir reservoir system. They introduced each consumer as a group of conflicts.

In this paper, three-reservoir operation has been considered to supply downstream demand of each reservoir. In the first part, to find existing conflicts, all reservoirs are operated at the same time, and then they are operated separately. In the second part, the Nash model has been applied as a conflict resolution model.

NASH CONFLICT RESOLUTION MODEL

The Nash model has been first identified by Nash (1950). In this model, stakeholder utilities are maximized at the same time.

$$Max.\quad f_1(U_K, d_K) = \prod_{K=1}^{n} (U_K - d_K) \qquad (1)$$

in which, $f_1 =$ a function that depends on U_K and d_K; $n =$ number of stakeholders (objectives); $U_K =$ utility value of K^{th} stakeholder; and, $d_K = K^{th}$ dimension of disagreement point.

Figure 1shows a linear relation between two groups of stakeholders. Thus, the utility of each stakeholder increases with a decrease in the other utility.

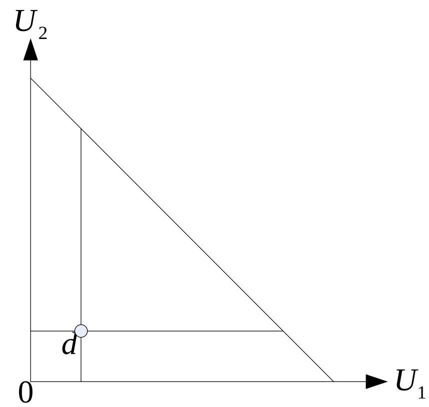


Figure 1. Position of utility values and disagreement point

In this paper, the coordinates of the disagreement point is zero for both stakeholders.

INTEGRATED WATER RESOURCES MANAGEMENT

Integrated water resource management (IWRM) is compromised of objectives, institutions, implementation, and adaptation (Davis 2007). Figure 2 shows different relations of the mentioned parts. Management of objectives is one of the aspects of IWRM that can effect to economic and social development and causes increasing project efficiency. The role of this option (management of objectives) is especially predominant when several institutions with different policies and laws are including in the project. Thus, identification of objectives, due to utility of each stakeholder (organization or group) needs to use an appropriate model.

Most water resources projects include conflicting objectives. Thus, governing of these objectives to increase all utilities is the final goal. Multi-reservoir operation includes conflicting objectives, in which release volume in each period depends on inflow and storage volume. In downstream reservoirs operation, upstream reservoir release volumes are added to aforementioned factors. So, conflicting among different objectives/stakeholders for upstream and downstream reservoirs may be acquired.

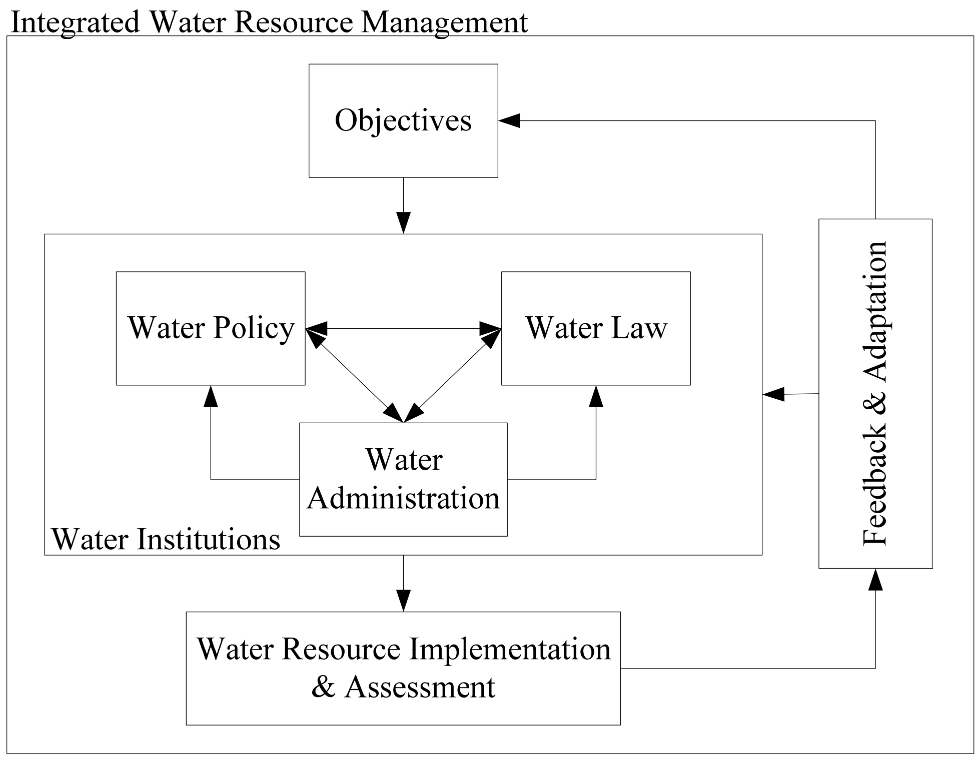


Figure 2. IWRM components (Davis 2007)

RESERVOIR SYSTEM OPERATION

Multi-reservoir system is one of the main complex cases in water resources management which involves different stakeholders. Each stakeholder can be appeared as a candidate of an organization, operator or consumer which their objectives are mostly conflicting. The objectives which can be commonly applied in reservoir system are hydropower generation, supplying downstream demands, flood control, and others. Each of the mentioned objectives can be used in a multi-reservoir system as the single-objective operation. In an operation model, types of operation in multi-reservoir system, especially in upstream and downstream reservoirs, are an important issue which can affect reservoir efficiency and is directly related to stockholder's utility.

OPERATIONAL MODEL

In this paper, two different types of operation model have been considered which different relations of stakeholders have been used on them. In these models, each reservoir has been connected to a stakeholder that its objective is supplying downstream reservoir demands.

The First Operational Model

In the first model, supplying downstream demands has been considered for all periods and reservoirs. Equation 2 illustrates minimization of the deviation of standard releases from the demand.

$$Min.\quad Z_1 = \sum_{i=1}^{N}\sum_{t=1}^{T}\left(\frac{De_{it} - R_{it}}{De_{it}}\right) \quad \forall RI_{it} < De_{it} \tag{2}$$

where, $T =$ number of operational periods; t = index illustrates considered period; N = number of reservoirs; i = index illustrates considered reservoir; $De_{it} =$ downstream demand of i^{th} reservoir at period t; and $R_{it} =$ downstream demand release of i^{th} reservoir at period t.

The Second Operational Model

In the second model, each reservoir is separately operated. Thus, three different objective functions have been used, as follows:

$$Min.\quad Z_{1i} = \sum_{t=1}^{T}\left(\frac{De_{it} - R_{it}}{De_{it}}\right) \quad \forall R_{it} < De_{it} \qquad for \quad i = 1,2,\ldots,N \tag{3}$$

where $Z_{1i} =$ the value of objective function for the i^{th} reservoir.

The continuity equation as a general relation illustrates the relationship between input and output volumes in reservoirs, as follows:

$$S_{i(t+1)} = S_{it} + Q_{it} + M_1.(R_{it}) + M_2.SP_{it} - Loss_{it} \tag{4}$$

in which, $S_{it} =$ storage volume of i^{th} reservoir at period t; $Q_{it} =$ inflow to i^{th} reservoir of i^{th} reservoir at period t; $M_1 =$ transfer matrix for downstream demand release; $M_2 =$ transfer matrix for volume of spilled water; $SP_{it} =$ volume of spilled water of i^{th} reservoir at period t; and, $Loss_{it} =$ volume of loosed water from i^{th} reservoir at period t.

The transfer matrix was first proposed by Wardlaw and Sharif (1999). The elements of this matrix are 0, 1, and -1 to operate a hydropower multi-reservoir system. The first type of release is for supplying the downstream demand of reservoirs. As shown in the M_1 matrix, a part of the release volume of upstream reservoir is allocated to downstream reservoir. In this paper, the a coefficient shows the mentioned volume.

$$M_1 = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ a & a & -1 \end{bmatrix} \tag{5}$$

The second type of release is a spill, in which 100 percent of the spilled water volume is transfer to downstream reservoirs. Thus, the M_2 matrix is used to show the relationship between spilled water of the reservoirs.

$$M_2 = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 1 & 1 & -1 \end{bmatrix} \quad (6)$$

The volume of loss from reservoir is related to the $Ev_{it} =$ evaporation depth of i^{th} reservoir at period *t* and $\overline{A_{it}} =$ average surface of reservoir of i^{th} reservoir at period *t*. f_2 is a function that uses to calculate the loss volume in all periods and reservoirs.

$$Loss_{it} = f_2\left(Ev_{it}, \overline{A_{it}}\right) \quad (7)$$

The average surface of the reservoir is calculated by $A_{it}, A_{i(t+1)} =$ water surface of i^{th} reservoir at start and end of period *t*, respectively, as follows:

$$\overline{A_{it}} = \left(A_{it} + A_{i(t+1)}\right)/2 \quad (8)$$

To calculate the water surface of each reservoir, a nonlinear relation is used.

$$A_{it} = f_3(S_{it}) \quad (9)$$

f_3 is a function which shows the relation between A_{it} and S_{it}. Other governing relationships of the system are as follows:

$$S_i^{Min} \le S_{it} \le S_i^{Max} \quad (10)$$

$$R_i^{Min} \le R_{it} \le R_i^{Max} \quad (11)$$

$$S_{i1} = S_{i(T+1)} \quad (12)$$

where, $S_i^{Min} =$ minimum storage of i^{th} reservoir; $S_i^{Max} =$ maximum storage of i^{th} reservoir; $R_i^{Min} =$ minimum allowable capacity for downstream release of i^{th} reservoir; and, $R_i^{Max} =$ maximum allowable capacity for downstream release of i^{th} reservoir.

MODEL APPLICATION

In this paper, optimal operation of three-reservoir system with objective of supplying downstream demands has been considered and different types of operation have been studied. In this model, each reservoir has been connected to a stakeholder with the objective of supplying downstream reservoir demands. In this section, a three-reservoir system in the Karoon Basin in Iran has been considered. Figure 3 shows schematic of three-reservoir system. In this system, the Bazoft and Karoon5 Reservoirs are located upstream, and the Karoon4 Reservoir is on the downstream side. A 12-month period with monthly average of a 40-year inflow series has been used as the inflow, as shown in Figure 4.

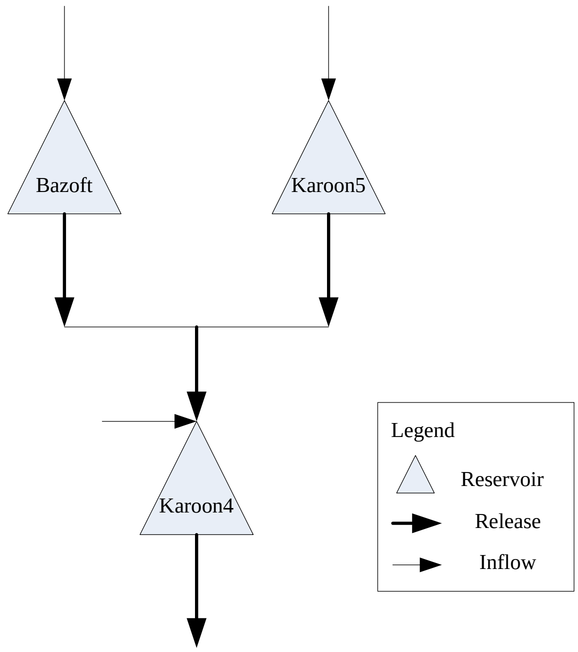


Figure 3. Schematic of three-reservoir system

To identify different types of operational effects, reservoirs are operated by two operational models, as defined above.

In the first operational model, the objective function is identified as minimization of the standard total positive deviation of release from downstream demands for each reservoir in all of the periods (Equation 2). The optimal objective function is 10.098 where the values of deviation from demand for the Bazoft, Karoon5, and Karoon4 are 1.058, zero, and 9.040, respectively.

The results show that the Karoon4 Reservoir has the most deviation between release and demand. To decrease this value, the water volume from upstream reservoir which is given to the Karoon4 Reservoir should be increased. But, upstream and downstream stakeholders are conflicting in the first type of operation model.

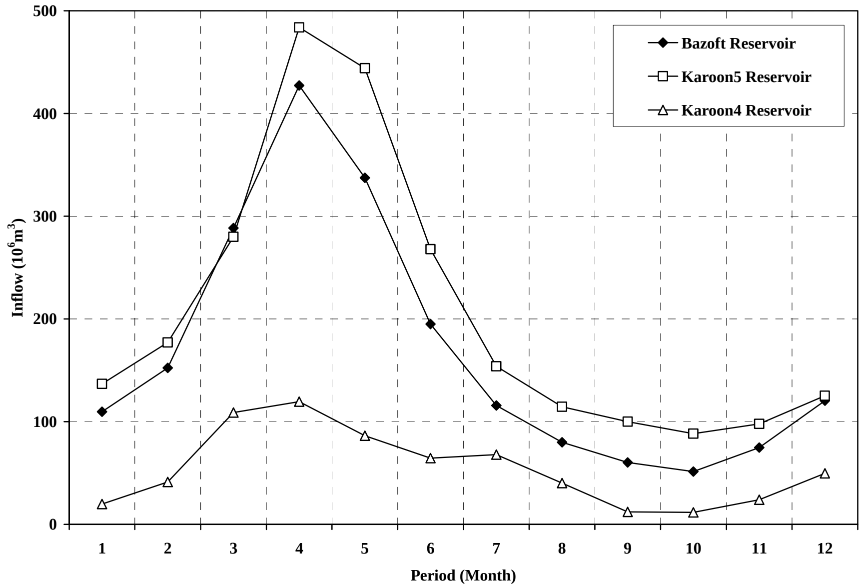
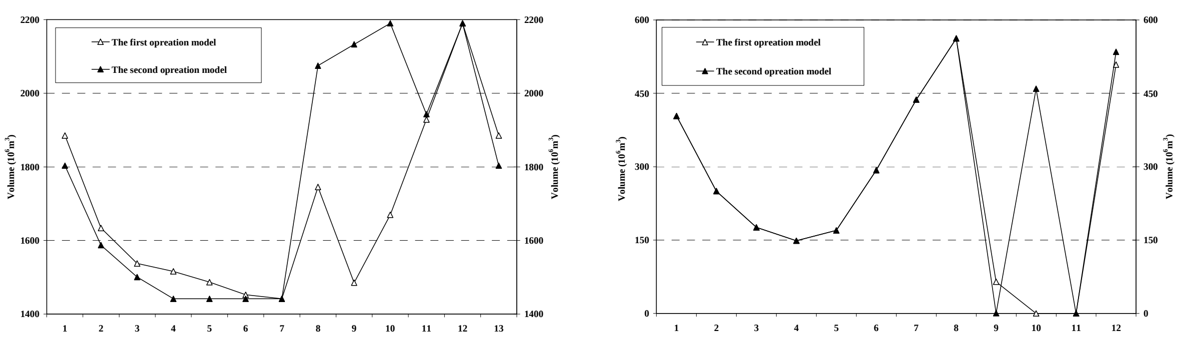


Figure 4. Reservoir system inflow

To find conflicts among stakeholders in the three-reservoir system operation, the results of the first operation model have been compared to those of the second operation model. If the reservoirs are operated separately, three different objective functions can be considered by Equation 3. In this model, the optimal values of Z_{11}, Z_{12} and Z_{13} are equal to 1.058, zero, and 7.232, respectively. The results show that supplying demand for downstream reservoir can be improved by the second type of operation. In other words, water volumes released from upstream reservoirs are used to satisfy the demand of the downstream reservoir. Figure 5 shows the release and storage volume for the downstream reservoir.



(a) (b)

Figure 5. The monthly water volume of the Karoon4 Reservoir: (a) storage, (b) release

Figure 5 shows a difference between release volumes, especially in the last months. The inflow volumes are in the minimum levels in these months, but in the second model the storage volumes are more than the same volumes in the first model. The releases of upstream reservoirs are the main reason. It means theses reservoirs should be operated to supply downstream reservoir demands.

APPLICATION OF THE NASH MODEL

The results of previous section show that objectives (stakeholders) of upstream and downstream reservoirs are conflicting. Thus, the Nash model has been used to overcome the existing conflicts. To introduce each stakeholder involving in a project, some utility functions have been applied. In this study, utility functions were used as follows:

$$U_K(Z_{1K}) = \frac{1}{12}\sqrt{12^2 - Z_{1K}^2} \qquad for \quad K = 1,2,3 \tag{13}$$

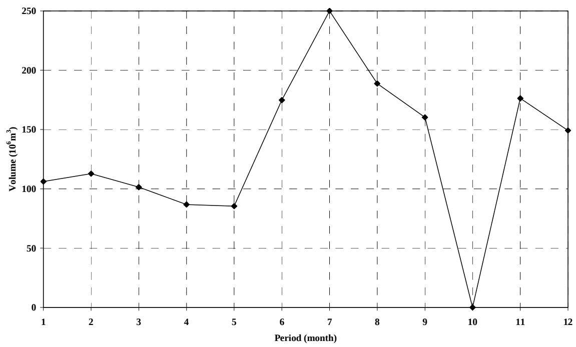
where $K =$ index that illustrates considered objective; $U_K(Z_K) =$ utility function of the K^{th} objective; and, $Z_{1K} =$ the K^{th} objective function.

By using this utility function, the highest (worst) value of objective function has been transferred to zero and the lowest (best) value to one. So, the Nash equation has been used as the objective function as follows:

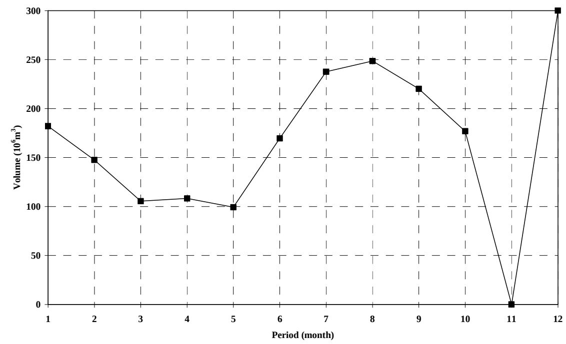
$$Max. \qquad f_4 = U_1 \times U_2 \times U_3 \tag{14}$$

Results show that the value of utilities U_1, U_2, and U_3 are 0.964, 0.942, and 0.698, respectively. This model can balance the utility of upstream and downstream reservoir stakeholders. Also, the utility (objective function) of upstream reservoirs are decreased and the utility of downstream reservoir is improved. Thus, the utility of all stakeholders have been increased at the same time, by using the Nash model. According to the results, the best strategy for finding appropriated decision making in operation of multi-reservoir system can be achieved by using a conflict resolution model.

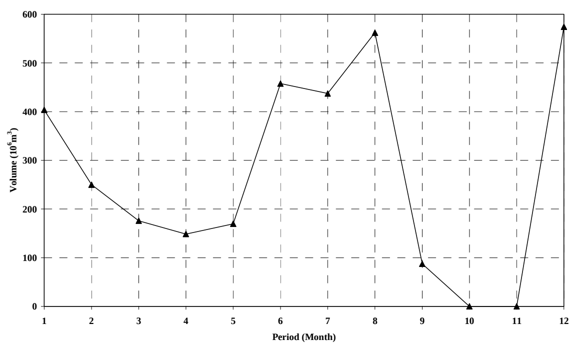
Figures 6 and 7 show the monthly releases and storages volume for compromised point of the Nash model.



(a)

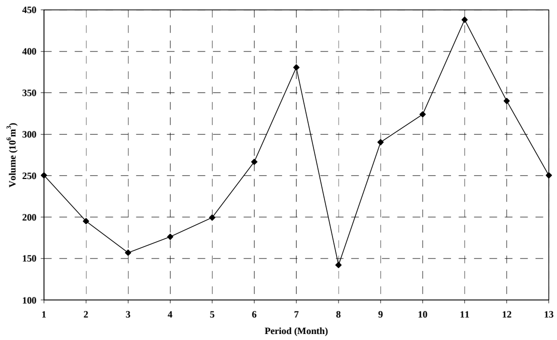


(b)

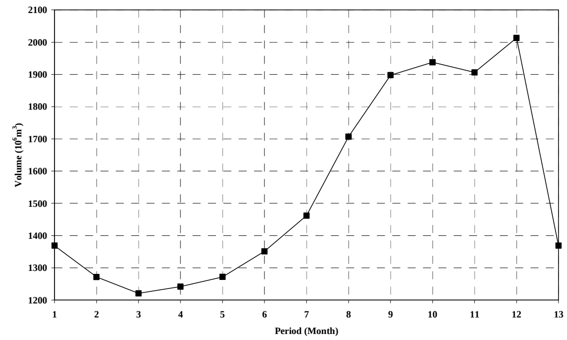


(c)

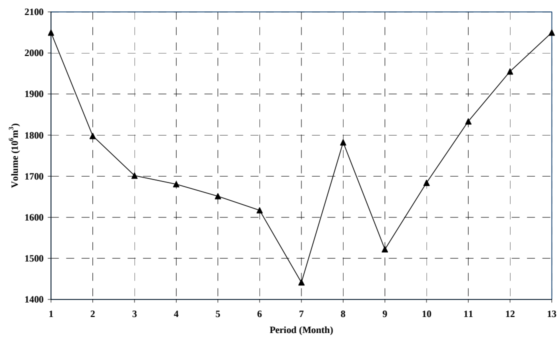
Figure 6. Monthly releases in the compromised point (a) the Bazoft Reservoir; (b) the Karoon4 Reservoir; and, (c) the Karoon5 Reservoir



(a)



(b)



(c)

Figure 7. Monthly storage volume in the compromised point (a) the Bazoft Reservoir; (b) the Karoon4 Reservoir; and, (c) the Karoon5 Reservoir

CONCLUSIONS

Water resources management is a sub-field of natural resources management in which different stakeholders are generally following their utilities. Thus, decision making depends on different stakeholder aspects. Each stakeholder is looking for its utility at the same time. Thus, the highest utility is a point of decision space which can appear possible utility for all stakeholders. The Nash model is a conflict-resolution model which can search a decision space and find a decision point.

Integrated water resource management (IWRM) is a process that introduces some technique to find appropriated decision. The type of objective is one of the effective factors that are identified by IWRM. Multi-reservoir system operation is one of the main fields of water resources management that involves different stakeholders. The stakeholder conflicts can especially appear in a system with both upstream and downstream reservoirs.

In this paper, operation of a three-reservoir with two parallel upstream reservoirs and a downstream reservoir in series has been considered. At the first step, two types of operation have been applied and the differences among stakeholders have been shown. Then, the Nash model was applied as a decision-making tool and each utility had been used separately. Results show that IWRM approaches with integrated objectives can help decision makers in maximizing system efficiency.

REFERENCES

Cai, X., Lasdon, L., and Michelsen, A. L. (2004). "Group decision making in water resources planning using multiple objective analysis." Journal of Water Resources Planning and Management, ASCE, 130(1), pp 4-14.

Davis, M. D. (2007). "Integrated water resource management and water sharing." Journal of Water Resources Planning and Management, ASCE, 133(5), pp 427-445.

Ganji, A., Khalili, D., and Karamouz, M. (2007). "Development of stochastic dynamic Nash game model for reservoir operation. I. The symmetric stochastic model with perfect information." Advances in Water Resources, 30, pp 528-542.

Ganji, A., Karamouz, M., and Khalili, D. (2007). "Development of stochastic dynamic Nash game model for reservoir operation. II. The value of players' information availability and cooperative behavior." Advances in Water Resources, 30, pp 157-168.

Heaney, J. P., and Dickinson, R. E. (1982). "Methods for apportioning the cost of a water resource project." Water Resource Research, 18(3), pp 476-482.

Labadie, J. W. (2004). "Optimal operation of multireservoir systems: state-of-the-art review." Journal of Water Resources Planning and Management, ASCE, 130(2), pp 93-110.

Nash, J. (1950). "The Bargaining Problem". Econometrica, 18 (2), pp 155–162.

Raquel, S., Szidarovszky, F., Coppola, E., and Rojano, A. (2007). "Application of game theory for a groundwater conflict in Mexico." Journal of Environmental Management, 84, pp 560-571.

Wardlaw. R. and Sharif, M., (1999). "Evaluation of genetic algorithms for optimal reservoir system operation." Journal of Water Resources Planning and Management, ASCE, 125(1), pp 25-33.

WATER PURIFICATION PROCESS AT CHILDREN ANTI-TUBERCULOSIS SANATORIUM IN ARAL SEA AREA: NUKUS CITY, REPUBLIC OF KARAKALPAKSTAN, UZBEKISTAN

Assoc. Prof. Vladimir Krepl, PhD[1], MSc
Dilmurod Gaybullaev[2*]

ABSTRACT

The shrinking of the Aral Sea has resulted in many problems, the two main being fresh water deficiency and pollution of water sources in the Aral Sea region. Most drinking water sources do not comply with water standards and the groundwater table is contaminated with a high level of salts and other minerals in Karakalpakstan (Aral Sea region, Uzbekistan).

Total dissolved salts (TDS) ranges from 0, 4 grams to 4–6 grams per liter (g/l), which is higher than the international standard for water mineral content (1, 5 g/l) for human consumption. The situation is dramatic in local hospitals and schools due to the poor water treatment technologies even in major cities of the region.

During the realization of the project "Improvement of the quality of drinking and irrigation water in the Aral Sea region by cleaning equipment and sorbents produced in the Czech Republic" various types of water treatment technologies were tested and the optimal water treatment (reverse osmosis) was found for implementing in the Republic's Children Anti-TB Sanatorium in Nukus city, Karakalpakstan.

Water purification operations and rebuilding sanatorium infrastructure were done in 2007–2008 (providing service for sustainability of water purification technologies) by Prote firm with the cooperation Czech University of Life Sciences, Institute of Tropics and Subtropics. The sanatorium is inhabited by 250–300 children in the summer and winter. The Sanatorium was chosen due to the very bad drinking water quality (TDS ranges 7–8 g/l) and poor water treatment technology, which created a high risk for children's health in the sanatorium. Reverse Osmosis treatment purifies TDS content of water from 7–8 g/l till 1, 5–2 g/l which makes favorable drinking and sanitation for children in the sanatorium.

Water purification technologies have had a very positive influence on the living conditions of the children in the sanatorium with safe water, achieving improved efficiency of the treatment of child patients and improved the sanitary –hygienic conditions at the sanatorium in the Nukus city, Republic of Karakalpakstan, Uzbekistan.

[1]Czech University of Life Sciences Prague, Institute of Tropics and Subtropics, Czech Republic
[2]Czech University of Life Sciences Prague, Institute of Tropics and Subtropics, 165 21 Prague 6 – Suchdol, Czech Republic, gaybullaev@its.czu.cz

INTRODUCTION

The Republic of Uzbekistan is situated in Central Asia, formerly part of the Soviet Union. Uzbekistan is the mostly populated country – about 27 million of inhabitants. (July, 2007). Major field of the national economy is industrial agriculture and mining industry, mainly oil and gas extraction.

The Aral Sea between Uzbekistan and Kazakhstan on east of the Caspian Sea used to be the fourth largest lake in the world. The Aral Sea has lost almost 75 percent of its water since 1960, which the water area was about 68000 sq. km reduced to 26 687 sq. km by 2003. The two rivers feeding, the Amu Darya and Syr Darya were diverted to irrigate cotton crops in Central Asia during the Soviet period. Between 1962 and 1991, the level of the Aral Sea fell by 16 meters. The Sea has receded up to 100 kilometers from its original shoreline.

The drying-out of the Aral Sea has resulted in the growing concentration of chemical pesticides and salt pans; these substances are then blown from the increasingly exposed lake and contribute to increased desertification. Other problems have approved in the Aral Sea region with the decreasing level of water in the Aral Sea meaning that fish resources are being lost, soil degradation is accruing, water salinization has increased, the number of wild animals has decreased, and local climate is changed. Cancers, lung disease and infant mortality are higher than they used to be because of drinking water is heavily polluted with salt.

The problem of fresh water and especially, drinking water is a major concern in the Aral Sea region, where desiccation of the Aral Sea has become an ecological catastrophe. Deficiency of quality in drinking water is not only due to inaccessibility and the poor quality of water from the natural sources, but also due to the poor water treatment technologies in the majority of the cities in the Aral Region. At most risks in this situation are groups of weak people who have low immunity – mainly the children.

MATERIALS AND METHODS

Area and research stages description

The main aim of the project is to provide clean and safe water in the Aral Sea regions in Uzbekistan. Concerning the state of portable and waste water management the many data was gathered, complied and evaluated to fulfill the goals.

Out of this data it is evident, that most of the people living in the region use low-quality potable water, not corresponding with the hygienic norms, mainly in the parameters of mineralization (salt amount), hardness and impurities of undissolved elements (sediments). The most at risk are the people with decreased immunity and mainly children. Water conditions are not safe and harmful for peoples' health in the Aral Sea area in the taken areas of water samples. From this point of view the Republican children anti-TB sanatorium was the worst places among the chosen places. Firstly, the groundwater salinity is worse then other places; secondly the sanatorium is directed towards the medical treatment of children who are suffering from tuberculosis illness.

The situation in potable water supply and management was critical. The potable water was highly contaminated by minerals (cca 1500mg/l), further there were problems with malfunctions water piping, with social equipment and partly non-factious sewerage. The salt water content is not favorable for drinking and local water purification technologies are not able to remove all soluble substances. From these reasons, the project executers cooperating with Uzbek government have decided to realize the project: the reconstruction of water management systems and water purification process at the Nukus children Anti-tuberculosis sanatorium in the Republic of Karakalpakstan, Uzbekistan.

Within the framework of the project, testing of various types of water treatment technologies was conducted in order to find the most advantageous method of water treatment, taking into account the quality of the water, but also considering the maintenance costs of the equipment.

For this purpose a Mobile Experimental Station was used. The MES has equipped laboratory and the water treatment devices which are used for laboratorial analyses and treatment of the chosen water samples.

<u>Gathering samples and results</u>

Gathered water samples are tested in both summer and winter periods and have used different types of water purification technology. Using different type of water purification technologies provided the opportunity to find out the best equipment for local conditions. The main water characteristics in the research were as follows: magnesium (Mg), calcium (Ca), chlorides, sulphates, dissolved substances, pH, temperature and conductivity.

One of the most important water characteristics for the water treatment technologies is the content of soluble substances. This chart shows the content of soluble substances in one of the samples taken from the water supply in the Children anti-TB Sanatorium in the town of Nukus. It also shows how the content of soluble substances changed after treatment with different types of water cleaning devices. Results of these tests are shown in Figure1. On the basis of the results the most suitable water purification equipment: Reverse Osmosis (AQUEL 400), ECO-120 and IVK (Uzbek product) was chosen for the further implementation of the project. This equipment reduces soluble substances in the water from 850 mg/l to 400 mg/l by cleaning of microbes and another water damage, which makes the water favorable for the local people and children in the anti-TB sanatorium. In addition we should mention here, that the water purification process was implemented in two stages: Producing technical and drinkable water. Technical water is used in the sanatorium for other household purposes for example washing, bathing, cooking and other purposes. Figure1 shows that the drinkable water is produced from the technical water.

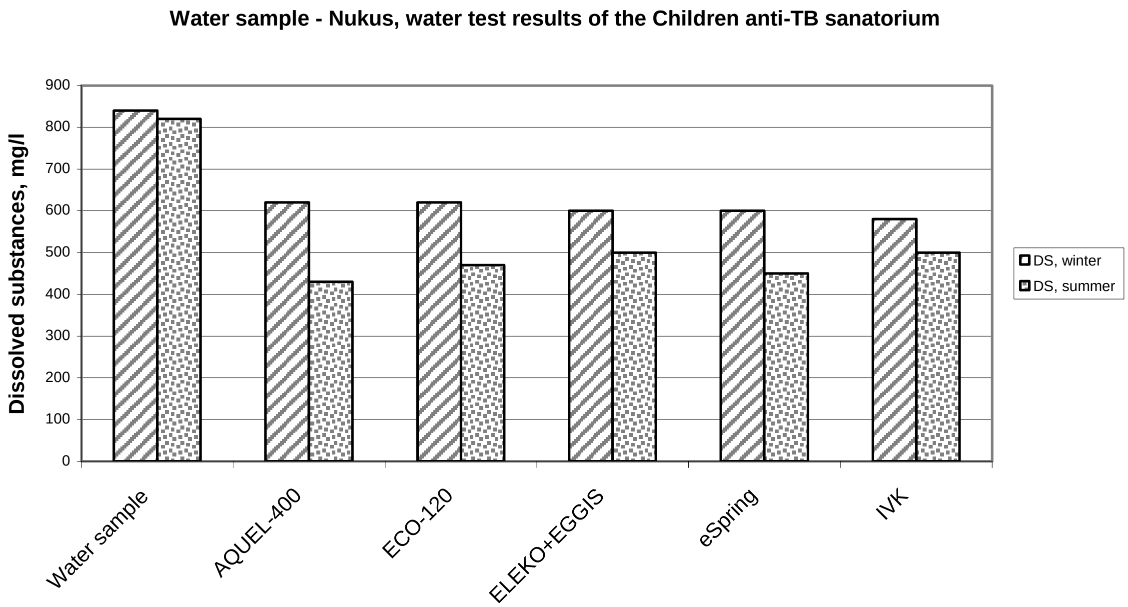


Figure 1. Results of water samples of the Children Anti TB sanatorium, Nukus city

Setting up the water purification operations

On the basis of supplemental agreement number 692/2007, from September 2007 Czech University of Life Sciences Prague, Institute Tropics and Subtopics in cooperation with PROTE company started water purification operations in the Children anti-TB Sanatorium in Nukus city which commenced operation during the 2008 summer period. The sanatorium is a tuberculosis treatment hospital is inhabited for 250 and 300 children during the winter and summer periods. Underground water was used to provide technical and drinkable water for the children in the sanatorium. After filling water tanks (50 m3 tank) and preparing tanks for technical and drinkable water, the purification process was started. According to the situation and the conditions of the sanatorium the process was divided into two stages: Producing technical water and producing drinkable water from the technical water.

The technical water is used for household purposes; these include bathing, cooking, and sanitation and so on. Drinkable water is used for local children to drink in the sanatorium.

RESULTS AND DISCUSSION

During the water testing and laboratory analyses the optimal water treatment method and equipment was found that could be used in high salinity area. For the local condition in this area the most effective devices were implemented with Czech products: AQUEL 400, ECO-120 and the Uzbek product: IVK system.

According to the local conditions of the sanatorium, for example the water pollution, the bad technical condition of water supply and the inefficient process of water purification the best water purification methods were used by Czech and Uzbek water purification technologies.

At first, suspended solids were removed by different type of mechanical filters which made the water favorable for children in the sanatorium. Water hardness was decreased with the Uzbek product (IVK filter) which made water softer then the other filters. The main work of water purification process (decreasing dissolved substance and salt) was carried out by a Reverse Osmosis system.

In some conditions, after water purification process there was done re-mineralization before the providing water to the children in the sanatorium.

As mentioned above, that the main water purification equipment Reverse Osmosis decreased dissolved substances from 850 mg/l to 400 mg/l (in some situations the water purification process was implemented twice from 7830 – 7950 mg/l dissolved substances of water to 850 mg/l drinking water) and the Uzbek IVK system controlled softness and minerals in the drinkable water.

Czech water purification equipment and technologies are comparable with those from other advanced countries and in some parameters (minimizing people factors, technology and know-how Czech provenance and in the matter of supply at a reasonable price and material in every country) is ahead of its competitors.

CONCLUSION

Sufficient for the quality drinkable water significantly decreases the poverty and the migration of the people in the Aral Sea. The Czech water purification technologies Reverse Osmosis (AQUEL 400), ECO-120 and Uzbek product (IVK) fully met local water purification requirements and standards. As we know, water quality can not be defined by the measurement of only one parameter. But, regarding these technologies safe and drinkable water was provided to the children and improved water management systems in the sanatorium.

The other benefit from the project is improvement of sanitary –hygienic conditions, training local staff for the protecting of natural environment and water management systems in the sanatorium.

Project implementation has had a very positive influence on the living conditions of the children. Of course, it is not possible to solve complex problem during the one project implementation period but from the given factors it is expected Czech water treatment technologies can be found the other regions in Uzbekistan and neighboring countries.

REFERENCES

Krepl V.: (2006), Project 81/04-06/MZe/B Report. Ministry of Agriculture of CR, Prague. 2006.

S.M. Aslov. International Fund for Saving the Aral Sea (IFAS) Initiatives in the Aral Sea Basin, the 3rd World

Water Forum Regional Cooperation in Shared Water Resources in Central Asia Kyoto, March 18, 2003

Carius A., Feil M., Tanzler D.: (2003). Adressing environmental risks in Central Asia. UNDP/Regional Bureau for Europe and the CIS. Report. 42 p. ISBN 92-990011-8-9

Embassy of CR in Tashkent, Uzbekistan, (2007), Uzbekistan – General territorial information, 74 p.

Genevieve M. Carr, James P. Neary: (2006), Water quality for ecosystems and human health, UNEP Global Environment Monitoring System (GEMS)/Water Programme. 132 p. ISBN 92-95039-10-6

WHO (2002), Public health initiatives – Investigation of gastro-intestinal diseases and water supply structures in Central Asian republics.

CIA World Fact book, Uzbekistan (2008)

NUMERICAL DESIGN PROCEDURE FOR MICRO-IRRIGATION MANIFOLDS

Gary P. Merkley[1]

ABSTRACT

A completely numerical design procedure for micro-irrigation manifolds was developed based on a variation of the hydraulic grade line method. The procedure determines pipe diameters and lengths for telescoping manifolds to minimize pressure variations and improve discharge uniformity. A computer program which implements the procedure is a free download from a web site. The software can accommodate a list of available pipe diameters and other parameters and options to constrain the design results within feasible limits, and it produces a graphical display of the design.

INTRODUCTION

Micro-irrigation laterals in most agricultural irrigation systems are connected to manifold pipes, and sometimes to headers which are in turn connected to the manifolds. The manifolds are sometimes thought of as sub-mains, and a primary design objective is that pressure variation along the manifolds is minimal (within reason) so that lateral inlet pressures are relatively constant, thereby providing better hydraulic performance of the system and better irrigation water management. Micro-irrigation laterals are most often of a single diameter, but manifolds may have several diameters, tapering down from larger to smaller pipe sizes.

There are various design approaches for manifold pipe sizing, including maximum velocity, hydraulic grade line (HGL), economic analysis, and others (Keller and Bliesner 1990). With the HGL method, up to four different pipe sizes are used along the manifold in an attempt to minimize pressure variation from the inlet to the downstream end. Pipe sizes (diameters) are selected from a list of available diameters such that the composite friction-loss curve closely approximates the slope of the ground surface in downhill-oriented manifolds. The HGL method has been applied in a semi-graphical form in the past, but in this paper it is shown how it can be applied through a completely numerical process, and implemented in a computer program.

SIZING OF MANIFOLD PIPES BY THE HGL METHOD

Along a micro-irrigation mainline pipe, there may be a combination of uphill and downhill portions of the manifold, thereby helping to balance pressures and provide less overall pressure variation. A combination of uphill and downhill manifold portions is often technically feasible when the average ground slope along the manifold is less than about 3%. In order to balance upstream and downstream pressures, it is always necessary for the downhill side of the manifold to be longer than the uphill side, except when the

[1] Professor, Civil and Environmental Engineering. Dept., Utah State Univ., Logan, UT, 84322; gary.merkley@usu.edu

ground slope is zero (in which case it is intuitive that the balance is achieved by having equal manifold lengths to either side of the mainline). When the average ground slope is above 3%, it is usually best to have only downhill manifolds because the uphill portion would be impractically short in length.

Uphill Side of the Manifold

On pipes running uphill, elevation change and friction loss combine to reduce pressure in the downstream direction. Thus, where there is an uphill portion of the manifold, it is best to determine the smallest allowable pipe diameter and use only the one diameter for this part of the manifold. The smallest allowable diameter is that which will provide the required lateral inlet pressure at the uphill end of the manifold, given a mainline pressure which is determined according to the design of the downhill portion of the manifold, as described below. This means that the available inlet pressure to most of the laterals on the uphill portion of the manifold will be higher than required, and throttling valves may be used to reduce this excess pressure at the lateral inlets. A different approach is to select the size of the uphill manifold pipe such that the average pressure is equal to the required lateral inlet pressure. In any case, it is also necessary to account for estimated local hydraulic losses at the point of connection of the laterals to the manifold. In the following, the length of the uphill portion of the manifold is given as x_u.

Downhill Side of the Manifold

This is the most complex part of the manifold design process, and it involves several steps, culminating in the development of a set of non-linear algebraic equations which must be solved iteratively for each pipe size to be included in the manifold. The length of the downhill portion of the manifold is represented herein by the variable x_d. The flow rate at the inlet to the downhill portion of the manifold is denoted as Q_m. The allowable pressure head variation in the manifold is defined as $(\Delta h_m)_a$, which is based on previous design calculations, taking into account a target emission uniformity (EU) and other parameters, including the lateral length and sizing. The allowable pressure head variation and the average ground slope, S_o, define an envelope within which the friction-loss curves must be confined, thereby achieving the target EU. This envelope is defined by a line representing S_o and a parallel line with a vertical offset of $(\Delta h_m)_a$ (Fig. 1).

Largest Pipe Size The largest pipe size will, of course, be at the connection to the mainline where the manifold flow rate is highest. This pipe diameter is represented as D_1. First, determine the minimum acceptable pipe diameter for the first section of the downhill side of the manifold. This can be accomplished by finding the inside pipe diameter, D, that will give a friction loss curve tangent to the ground slope (Fig. 1). To do this, it is necessary to:

(1) have the slope of the friction loss curve equal to S_o; and,
(2) have the "h" values equal at this location (make them just touch at a point).

where S_o is the average ground slope along the manifold; and, H is the pressure head in the manifold. The elevation change along the downhill portion of the manifold is ΔE_m, as shown in Fig. 1, and is equal to $S_o x_d$.

These two requirements can be satisfied by applying two equations, whereby the two unknowns will be the flow rate, Q, and the inside diameter, D_1. Here, it is assumed that the lateral inflow rate, Q_l, is constant along the length of the manifold.

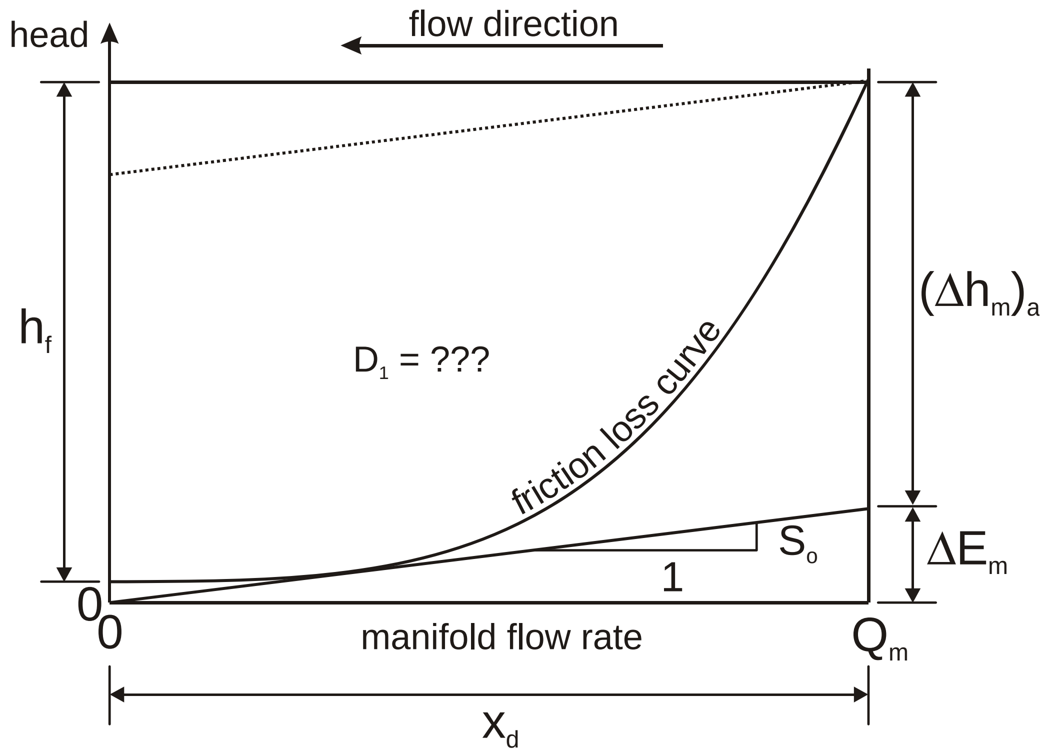


Figure 1. Schematic diagram of the friction-loss envelope for manifold pipe sizing.

In Fig. 1, where the right side is the mainline location and the left side is the downstream closed end of the manifold, the manifold flow rate varies from Q_m to zero, and the friction loss curve is defined as:

$$h = \underbrace{\left(\Delta h_m\right)_a + \Delta E_m - h_f}_{\text{constants}} + \underbrace{\frac{JFL}{100}}_{\text{varies with distance}} \tag{1}$$

where, $0 \le L \le x_d$. So, when L = 0, h equals the first three terms of Eq. 1, and the calculations move upstream as L increases. Using the Hazen-Williams (Brater and King 1976) pipe friction-loss equation,

$$J = K\left(\frac{Q}{C}\right)^{1.852} D^{-4.87} \quad \text{for} \quad 0 \le Q \le Q_m \tag{2}$$

$$F = \frac{1}{2.852} + \frac{1}{2N} + \frac{\sqrt{0.852}}{6N^2} \tag{3}$$

$$N = \left(\frac{x_d}{S_l}\right)\left(\frac{Q}{Q_m}\right) \quad \text{for} \quad N > 0 \tag{4}$$

where F is a factor for multiple-outlet pipes (Keller and Bliesner 1990); and, N is the number of outlets (laterals) from the location of Q in the manifold to the downhill closed end. The length to be used in Eq. 1 is:

$$L = x_d\left(\frac{Q}{Q_m}\right) \tag{5}$$

The total friction head loss in the downhill side of the manifold is:

$$h_f = \frac{J_{hf} F_{hf} x_d}{100} = 0.01K\left(\frac{Q_m}{C}\right)^{1.852} D^{-4.87} F_{hf} x_d \tag{6}$$

where F_{hf} is defined as F above, except with $N = x_d/S_l$. For Q in lps and D in cm, $K = 16.42(10)^6$.

The slope of the friction-loss curve is (applying the "chain rule" of calculus):

$$\frac{dh}{dQ} = \frac{1}{100}\left(FL\frac{dJ}{dQ} + JL\frac{dF}{dQ} + JF\frac{dL}{dQ}\right) \tag{7}$$

where,

$$\frac{dJ}{dQ} = \frac{1.852KQ^{0.852}}{C^{1.852}D^{4.87}} \tag{8}$$

$$\frac{dF}{dQ} = -\frac{x_d}{S_l Q_m N^2}\left(\frac{1}{2} + \frac{\sqrt{0.852}}{3N}\right) \tag{9}$$

$$\frac{dL}{dQ} = \frac{x_d}{Q_m} \tag{10}$$

Here it is noted that dh/dQ ≠ J. Also, the ground surface (assuming a constant ground slope, S_o) is defined by:

$$h = S_o L = S_o x_d \left(\frac{Q}{Q_m} \right) \tag{11}$$

and,

$$\frac{dh}{dQ} = \frac{S_o x_d}{Q_m} \tag{12}$$

Combine the two equations defining h (Eqs. 1 and 11), effectively causing the friction loss curve to just touch the ground surface line:

$$S_o x_d \left(\frac{Q}{Q_m} \right) = \left(\Delta h_m \right)_a + \Delta E_m - h_f + \frac{JFL}{100} \tag{13}$$

Solve Eq. 13 for the pipe inside diameter, D:

$$D = \left[\frac{100\, C^{1.852} \left(\frac{S_o x_d Q}{Q_m} - \left(\Delta h_m \right)_a - \Delta E_m \right)}{K \left(Q^{1.852} FL - Q_m^{1.852} F_{hf} x_d \right)} \right]^{-0.205} \tag{14}$$

Then, set the slope of the friction loss curve equal to $S_o x_d / Q_m$:

$$\frac{S_o x_d}{Q_m} = \frac{1}{100} \left(FL \frac{dJ}{dQ} + JL \frac{dF}{dQ} + JF \frac{dL}{dQ} \right) \tag{15}$$

Combine Eqs. 14 & 15 so that the only unknown is Q (note that D appears in the J and dJ/dQ terms of Eq.). Based on the assumption of constant lateral inflow rate, Q_m is a known value. Solve for Q by iteration. The required pipe inside diameter, D, will be known as part of the solution for Q. The calculated value of D is the minimum inside pipe diameter, so find the nearest available pipe size that is larger than or equal to D:

$$D_1 \geq D \quad \& \quad \text{minimize} \left(D_1 - D \right) \tag{16}$$

Slope of the Tangent Line Next, calculate the equation of the line through the origin and tangent to the friction loss curve for D_1. Let S_t be the slope of the tangent line:

$$h = S_t L = S_t x_d \left(\frac{Q}{Q_m} \right) \tag{17}$$

then,

$$S_t x_d \left(\frac{Q}{Q_m} \right) = \left(\Delta h_m \right)_a + \Delta E_l - h_f + \frac{JFL}{100} \tag{18}$$

Set the slope of the friction loss curve equal to $S_t x_d / Q_m$:

$$\frac{S_t x_d}{Q_m} = \frac{1}{100} \left(FL \frac{dJ}{dQ} + JL \frac{dF}{dQ} + JF \frac{dL}{dQ} \right) \tag{19}$$

Combine the above two equations to eliminate S_t, and solve for Q. Calculate the slope, S_t, directly.

Smaller (Downstream) Pipe Sizes Then take the next smaller pipe size, D_2, and make its friction loss curve tangent to the same line (slope = S_t):

$$h = h_0 + \frac{JFL}{100} \tag{20}$$

where H_0 is a vertical offset to make the friction-loss curve tangent to the S_t line, emanating from the origin. Equating heads and solving for h_0,

$$h_0 = S_t x_d \left(\frac{Q}{Q_m} \right) - \frac{JFL}{100} \tag{21}$$

Again, set the slope of the friction loss curve equal to S_t:

$$\frac{S_t x_d}{Q_m} = \frac{1}{100} \left(FL \frac{dJ}{dQ} + JL \frac{dF}{dQ} + JF \frac{dL}{dQ} \right) \tag{22}$$

Solve the above equation for Q, then solve directly for h_0. This gives the equation for the next manifold friction-loss curve. Determine the intersection with the D_1 friction loss curve to set the length for size D_1; this is done by equating the h values for the respective equations and solving for Q at the intersection:

$$h_{big} - h_{small} + \frac{FLK}{100}\left(\frac{Q}{C}\right)^{1.852}\left(D_{big}^{-4.87} - D_{small}^{-4.87}\right) = 0 \tag{23}$$

where, for the first pipe size (D_1):

$$h_{big} = \left(\Delta h_m\right)_a + \Delta E_l - h_f \tag{24}$$

and for the second pipe size (D_2):

$$h_{small} = h_0 \tag{25}$$

and F & L are as defined in Eqs. 3 to 5. Then, the length of pipe D_1 is equal to:

$$L_{D1} = x_d\left(1 - \frac{Q}{Q_m}\right) \tag{26}$$

Continue this process until there are three or four manifold pipe sizes, or until arriving at a pipe size that has $D < ½D_1$.

Figures 2 and 3 show images from a computer program (using sample data) which applies the fully numerical HGL method for manifold pipe sizing. The computer program which applies this manifold design methodology based on the Hazen-Williams equation can be downloaded at www.neng.usu.edu/bie/faculty/merkley/BIE6110.htm.

SUMMARY AND CONCLUSIONS

A completely numerical HGL design methodology was developed for pipe sizing in micro-irrigation manifolds, and was implemented in a computer program with tabular and graphical results. The methodology provides for relatively uniform pressure along the downhill portion of a manifold by selecting the most appropriate pipe diameters and lengths, thereby resulting in the achievement of relatively high emission uniformity from the irrigation system.

The above equation development can also be done using the Darcy-Weisbach pipe friction-loss equation. It is necessary to specify a minimum length for each pipe size in the manifold so that the design is feasible. For example, the minimum allowable pipe length might be $5S_l$. The friction loss curves must be shifted vertically upward to provide the correct average (or minimum, if pressure regulators are used) pressure in the manifold; this shifting process determines the required manifold inlet pressure head, h_m.

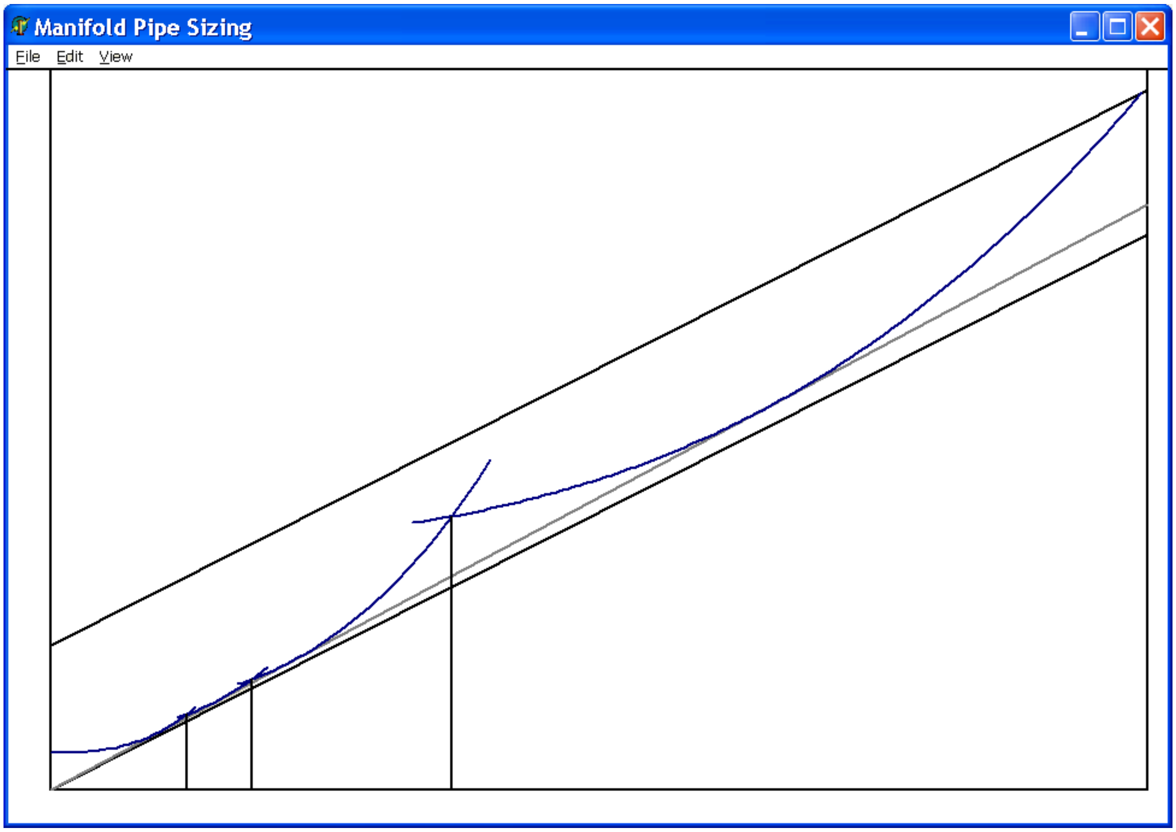
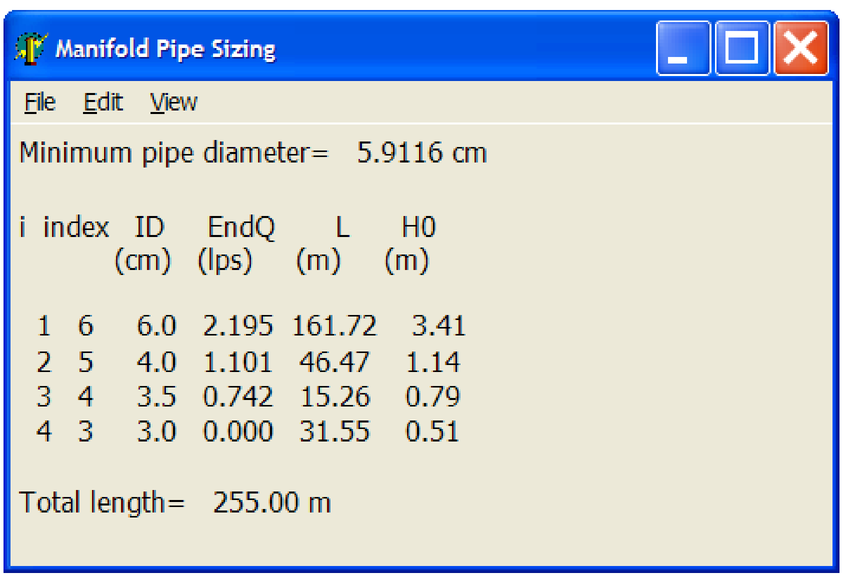


Figure 2. Schematic display of a manifold design solution from a computer program.



Minimum pipe diameter= 5.9116 cm

i	index	ID (cm)	EndQ (lps)	L (m)	H0 (m)
1	6	6.0	2.195	161.72	3.41
2	5	4.0	1.101	46.47	1.14
3	4	3.5	0.742	15.26	0.79
4	3	3.0	0.000	31.55	0.51

Total length= 255.00 m

Figure 3. Tabular results of a manifold design program in a computer program.

REFERENCES

Brater, E.F., King, H.W. 1976. Handbook of Hydraulics. 6th Ed. McGraw-Hill Book Co., New York, NY.

Keller, J, Bliesner, R.D. 1990. Sprinkle and Trickle Irrigation. Van Nostrand Reinhold, New York, NY. Currently available from Keller-Bliesner, LLC, Logan, UT. 651 pp.

ALTERNATE MANAGEMENT STRATEGIES FOR REDUCTION OF BOD ALONG THE RIVER BURIGANGA, BANGLADESH

Md. Ashiqur Rahman [1]
Tihomir Ancev, PhD [2]
Dhia Al Bakri, PhD [3]

ABSTRACT

The river Buriganga is a prime example of serious surface water pollution problems in Bangladesh. Currently, the river carries only wastewater in the months (November to April) of the dry season becoming toxic. The level of pollution is so high that no aquatic species can survive in it and the situation is becoming worse day by day. So far the emphasis of the pollution management has been solely on the application of command-and control-based mechanisms, however little or no success has been achieved as the polluters seem to be reluctant to adopt the mechanism without having any economic incentive. This multidisciplinary study examines and compares the effectiveness of three different management strategies: uniform reductions, uniform emission charges and ambient-based permit system.

The transfer coefficients of the oxygen demanding wastes were calculated from the Streeter Phelps model of dissolved oxygen concentration. The total abatement cost functions were assumed to be quadratic, which implies linear marginal abatement cost functions. These functions were calculated through the regression analysis of square values of the biological oxygen demand (BOD) removed and the abatement costs. The spreadsheet is developed in Excel with mathematical programming model for the purpose of simulating the effects of three types of strategies designed to reduce emissions of BOD and subsequently to increase dissolved oxygen (DO), thereby improving the river water quality. The results are presented for the evaluation of three alternative strategies to achieve a given target at least costs.

BACKGROUND AND INTRODUCTION

Dhaka City, the capital of Bangladesh, stands on the banks of the river Buriganga. In 1610 the city was established as a provincial capital of the Mughal rulers on the Northern bank of this river. However, the city's existence can be traced back to the 7th century when the township is known to have existed as a small riverside settlement. The city has since developed gradually on the North and eastern banks of the Buriganga river. The hydrology of this river is influenced by the tide and its flow is dominant by many upstream rivers and tributaries like Jamuna, Turag, Dhaleswari, Kaliganga, Balu rivers

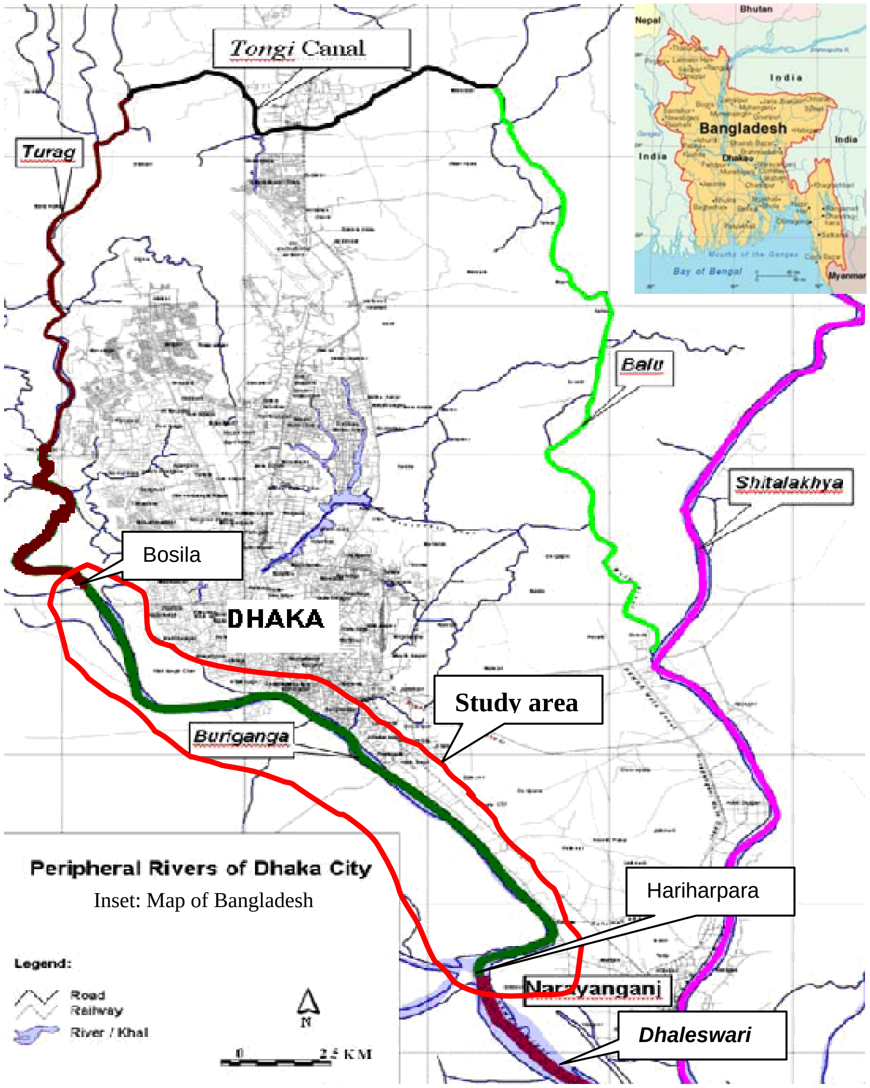
[1] PhD candidate, Faculty of Agriculture, Food and Natural Resources (FAFNR), The University of Sydney, NSW 2006 Australia; ashiq.rahman@usyd.edu.au
[2] Senior Lecturer, Resource and Environmental Economics, FAFNR, The University of Sydney, NSW 2006 Australia; t.ancev@usyd.edu.au
[3] Senior Lecturer, Land and Water Science, FAFNR, The University of Sydney, NSW 2006 Australia; d.bakri@usyd.edu.au

and Karnatali khal (Figure 1a). The river Buriganga originates at Bosila (at a distance of about 3km from Gabtoli bridge) from the river Turag, which flows along the western boundary of Dhaka City and finally meets the Dhaleswari river at Hariharpara.

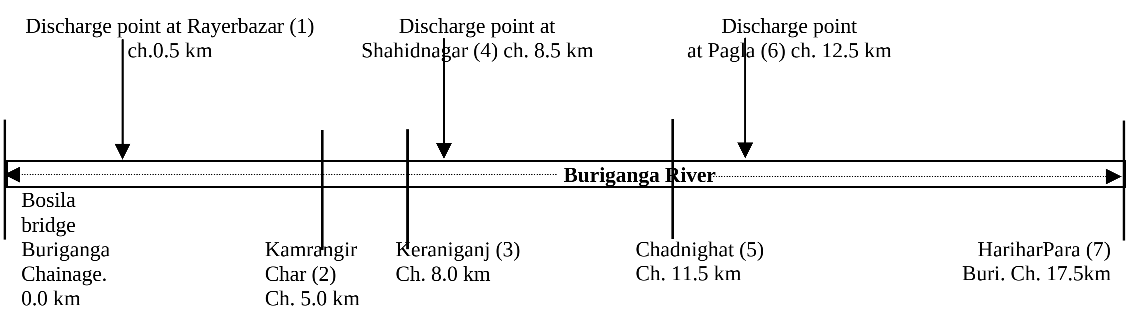
This river acts as a main drainage outlet as well as navigational route for important commercial activities of Dhaka city and thus is an integral part of the city's urban landscape, history, economy and ecology. The river has been the key source of water supply, ground water recharge, and fishing and recreation site along with playing an important role in flood control for Dhaka City. The river has also been used for agricultural, sanitary and industrial purposes (Alam 2008). However, over the years and especially since the 1980s, unplanned urbanisation, industrialisation and population pressure along the river have adversely affected the river's flow and ecological function. The current population density along the river drainage area is extremely high, around 46,000 people per sq. km (Wikipedia 2009). There are reports that about 80 percent of this population do not have the sewerage treatment facilities and the untreated effluent directly goes into the Buriganga through the waterways along the river (SWMC 1995). Moreover, most of the small and medium scale industrial enterprises especially tanneries and textiles located along the banks of the river lack of having any effluent treatment facility and thus are also contributing to the pollution of this river.

Previous studies (Ahmed and Mohammed 1988; Browder 1992; Kamal et al. 1999; Rahman and Hossain 2007) on the assessment of the state of pollution of the River Buriganga suggest that the sprawling residential growth and the development of industries have caused the rapid degradation of the water quality of Buriganga. These studies have pointed that in the present conditions this river carries only wastewater in the months (November to April) of the dry season becoming toxic during this period. The level of pollution is so high that no aquatic species can survive in it and the situation is worsening everyday. The studies have also identified that the oxygen demanding organic wastes cause the maximum damage to this river water quality in terms of the DO[4] (dissolved oxygen). This present research focuses on the BOD[5] (Biological Oxygen Demand) to analyse the alternate management strategies to control this specific pollutant.

[4] A naturally occurring concentration of DO for the Buriganga river is assumed as 8 mg/L.
[5] BOD is the amount of dissolved oxygen required by the bacteria to breakdown a certain amount of organic waste (Masters 2004). Therefore, as more BOD is discharged in the river, it reduces the amount of DO in the river. In this research, all BOD values of the water samples were measured at 5 day 20^0C temperature.



(a)



(b)

Figure 1. (a) Buriganga river system (b) Schematic diagram of the river segment showing locations of wastewater discharge points and river receptor points (the numbers in the parentheses represent the station nos.)

The Government of Bangladesh has enacted requisite rules and regulations (EDA 1999; Farooque and Hasan 1996) to end the harmful practices of discharging untreated and uncontrolled effluent directly into the river; however, so far the enforcement status of the regulations is likely to be very poor as the trend of pollution of this river has not been decreased at all over the years (Magumdar 2005). From pollution management perspectives of this river, so far emphasis has been given solely on the application of command and control (CAC) based mechanism, however little or no success has been perceived as the polluters seem to be reluctant to adopt the mechanism without having any incentive. Though it seems that absence of any proper effluent treatment facility and failure of the authority to enforce requisite rules and regulations are apparently the main reason for the degradation of the water quality of Buriganga, the practical solution may lie somewhere else.

Researches were conducted on to finding out ways for the improvement of Buriganga river water quality which were basically focused on to the technological solution of the problem. Those have either recommended the establishment of effluent treatment plants (Rahman & Rana 1996) or, relocation of polluting industries (BKH 1995) or, augmentation of dry season flow from the Jamuna River (BWDB 2004). The practicality is that none of those solutions could have yet been implemented and moreover, those measures raised confusions regarding their cost effectiveness and sustainability. Thus questions and confusions have arisen regarding the applicability and effectiveness of alternate economic incentive (EI) based management strategies from economic and environmental perspectives in developing countries like Bangladesh. This has necessitated the issue of researching and analysing on the alternate management strategies for reduction of specific pollutants in the river Buriganga.

Furthermore, the growing consciousness at the global level and in particular since the inception of Agenda 21 (Chapter 30) has produced a new concept of pollution management in different sectors of economic activities around the world (UNDSD 1992). In the new concept, conventional pollution control system where the focus is given on CAC approach is replaced by Economic Incentive (EI) based proactive approaches. This paradigm shift has been successful in many industrialized and developed countries (World Bank 2000; Delmas 2002). However, so far the response to the new concept in developing countries, including Bangladesh is mixed and at the same time much confusion and disagreements have arisen regarding formulation of strategies for pollution control in those countries (Asolekar 2002; Rathi, 2003; Dattagupta, 2004; Krishnamoorthy, 2005).

This study has selected three different management strategies, which are uniform reduction in effluent discharges, uniform emission charges (Pigou 1962) and non-uniform ambient based emission permits (Kolstad 2000) to empirically analyse and compare their effectiveness for the reduction of BOD in the river Buriganga. The research in particular focuses on a spreadsheet simulation exercise, which is ideal for the process because the entire worksheet and also the graphs are recalculated each time of meeting alternative water quality standards. Finally, the results are presented in this paper for the evaluation of three alternative strategies to achieve a given target at least costs.

ALTERNATE MANAGEMENT INTERVENTIONS

From policy perspectives, there are two main types of instruments used to control pollution. The first type is regulatory standards and controls, which is traditionally referred to as CAC based approach and the second type is market based mechanism, which are referred to as EI approaches. Generally, CACs (laws mandating generators of all pollutants to ensure a pre-determined uniform reduction level) are the most popular and traditional approach to controlling environmental pollution. They rely heavily on setting various quantitative and qualitative controls and regulations to limit polluters' behaviour. These controls and regulations usually contain uniform reduction in effluent discharges which are implemented as pollution quotas, licenses and standards (Field 1994; Pu 2003). This CAC type of regulation sets uniform targets for how much effluent a particular source should emit, often by dictating the processes that should be used in their facilities. However, this approach gives the pollutant generators little incentive to act on a long term basis to change the processes which cause pollution. A further disadvantage is that CAC regulations often suppress innovation and maintain inefficient types of production because any impact these measures have on income tend to be indirect (FCE 1994). By the early 1990s, regulators in many developed countries had concluded that traditional CAC methods were too expensive and often ineffective (Austin 1999; World Bank 2000). Moreover, the CAC regulations limit the quantity of regulations, but leave the method of control to the polluter and these regulations rely heavily on technology (Jaeger 2005).

On the other hand, the EI based mechanism such as uniform emission charges and non-uniform ambient based emission permits discourage pollution with monetary incentives. In these systems, polluters are not told how much they can pollute or what technology they must use, but their choices will have financial consequences, and this will influence the choices they make. With these policies, emission constraints are not source specific; rather they provide equal incentives to all polluters by increasing the marginal costs of pollution (Eskeland and Jimenez 1992). Economists argue that these instruments can create a system for pollution reduction that achieves the same level of environmental protection for a lower overall cost (Pearce and Turner 1990; Austin 1999). These alternate instruments for pollution control have been in textbooks for as long as conventional regulations, but the use of EI for pollution control to date has been confined to relatively few applications (Austin 1999). Jaeger (2005) has argued that application of EI may offer several advantages over CAC, such as providing incentives for environmentally sound behaviour, raising revenue to help finance pollution control activities and ensuring that water quality objectives are achieved at the least possible cost to society. Moreover, Oates et al. (1989) have pointed that EI can achieve a given level of environmental protection for lowest overall cost by creating a framework that allows for differential response by polluters depending on their ability to make reductions.

In spite of several benefits of EI over CAC, it is not an easy task to implement any such alternate management strategy especially in a developing country, as in most cases the pollution control agencies of these countries have many problems with information and transaction costs[6]. For example, the design of an optimal pollution charge is a difficult task, as it requires the existence of a reasonable database and information about the exact quantity and quality of the discharged wastewater (Kraemer 1995). However, Afsah et al. (1996) pointed that once regulators have more integrated information systems, more capacity for setting priorities and a stronger public mandate, it will not be difficult for them to manage pollution more cost effectively. Furthermore, Larsen and Ipsen (1997) asserted that the prerequisites for the successful implementation of most EI are appropriate standards, effective administration, monitoring and enforcement capacities, institutional coordination and economic stability. Nevertheless, Kathuria (2006) strongly argues that despite of all these limitations, the potential (theoretical) benefits of using EI may clearly outweigh the costs involved in meeting any prerequisite.

METHODOLOGY, ANALYTICAL TECHNIQUES AND RESULTS

Selection of Discharge and Receptor Points

In this study, three main discharge points and four receptor points (sampling locations) were selected along the river Buriganga to respectively assess the quality of waste water and river water in terms of BOD and DO. These sampling locations are illustrated in Figure 1b. The field work was conducted on five different occasions (both for discharge and receptor points) in the dry season (low flow period) from November, 2008 to February 2009. The urban and economic settlement along both the banks of this river has increased the potential of pollution from numerous number of point and non-point (diffused) sources falling into this river system, originating either from industries or from domestic wastes. Moreover, absence of adequate sewage management system within the municipal area along the river banks further enhances the possibility of this kind of pollution. However, in reality it is very difficult and time consuming to compute pollution loadings and flow rates separately from all of these sources. Therefore, certain criteria were considered while selecting the discharge points for assessing the impacts of BOD loads into this river. The deciding criteria were the visible effects of river pollution during the field visits; the practicality of measurement of wastewater flows and collection of samples from technical point of view; and the extent of pollution load and wastewater flow rate as revealed in previous studies. On the basis of these criteria, the three discharge points which were believed to contribute most in terms of pollution load were selected as: Rayer bazar sluice gate; Shahidnagar drain points; and the outfalls of the Pagla Sewage Treatment Plant (PSTP). Further information on these three major polluting sources have been provided in Appendix 1. Since it was not possible to compute loadings from all the points of wastewater effluent through measurement of flows directly, it was necessary to estimate and compare the total loadings, arising out of contributing areas, which might be discharged into the nearby system (dry method). This methodology is further discussed in the next section. Contrary to the discharge points, the selection of receptor points was relatively simpler and easier. The receptor points were selected at Kamrangirchar, Keraniganj, Chadnighat and Hariharpara. These are significant points (washing/bathing site, landing station, urban centres, intake point for

---

[6] These are the costs incurred in attempting to complete any economic transaction; for example, the administrative costs or the value of the time expended in any negotiation (Stavins 1995).

water supply) where the ambient water quality is of great importance to the regulator, Department of Environment (DOE) in Bangladesh. In addition to these points, sampling was also done at Bashila to understand the phenomena of the water quality at the upstream end of this river. The sampling locations of receptor points are also shown in Figure 1. The distances among the sampling locations were estimated from the chainage points of the Water Development Board (WDB).

Assessment of Water Quality

As per the DOE and the Environmental Protection Agency (EPA) of USA a range of assigning grades (A, B, C, D and U) was set for the indication of water quality of the river by associating the water quality with the different use levels as mentioned in Table 1. The DO levels at the receptor points were assessed through in situ measurements with the DO probe and the water samples were collected (both from receptor and discharge points) for testing of the BOD (5 day 20^0C) concentration in the laboratory by following the APHA (2005) guidelines. The historical data on DO and BOD levels and river flow rates (rating curves) were also procured from the secondary sources like the DOE (Department of Environment) and BWDB (Bangladesh Water Development Board) to assess the pollution trend in this river. The discharge rate of waste water at the major discharge points were carried out by the float method (Gore 2007). The wastewater discharge and concentration of BOD levels have been used for wet loading estimates as follows:

Loading (wet method) = Flow discharge * concentration

Dry loading estimates for the BOD was also calculated (Appendix 2) using available information on drainage zones (sub-catchment) and sewerage treatment facility within the river catchment area (JICA 1991; Browder 1992; DWASA 1998). Sub-catchment wise total and unsewered population were obtained from these studies and maps. Moreover, the major water polluting industries have been identified, and pollution discharges from these industries have been estimated from the previous studies (BKH 1995). Thus the total loading through this method was estimated as following:

Loading (dry method) = Per capita wastewater production x Number of inhabitants (in a drainage zone) * % of population unsewered + contribution from industries

Finally, different dry and wet loadings for BOD were compared to assess the extent of agreement among the loadings computed using different data and it was revealed that there were reasonable agreement (within 10% variation) between dry and wet loadings (Table 2). The higher values (wet method) of BOD loadings were considered to use for further economic analysis to ensure the optimal design on the application of pollution control instruments.

Table 1. River Water Quality Classes in terms of Minimum DO Level for Different Use Levels

Quality class	Minimum DO (mg/L)	Description
A	>7	Public Water Supplies, excellent quality
B	5	Suitable for swimming, excellent aesthetic value
C	3.5	Wildlife habitat, indigenous fishing
D	2	Not objectionable, OK for navigation, industrial uses
U	<2	Unacceptable, likely to be offensive

Table 2. BOD Loadings at the Discharge Points

Discharge points	Estimated flow rate (m^3/s)	Average BOD concentration (mg/L)	Average BOD load (000 lbs/day)		% difference between wet and dry methods
			Wet method estimation	Dry method estimation[b]	
Rayerbazar	0.995	578	109.0	109.96	0.26
Shahidnagar	0.819	505	78.7	71.65	9.78
Pagla	1.476	170	47.7	43.32	10.08

[b]Detailed calculation of dry method is provided in Appendix 2

DO Transfer Coefficient for Discharge-Receptor Pairs

The transfer coefficients are used in simulating pollutant flows. It relates the degree to which pollution concentrations at a specific receptor site are increased by a one-unit increase in emissions from a specific source (Tietenberg 2006). The nature of the pollution in this study is that it is a spatially distributed pollution, so the effluent discharges do not affect the quality of water at the point of discharge, but rather affect the quality downstream. The transfer coefficients of the oxygen demanding wastes were calculated from the Streeter Phelps model of DO concentration (Streeter and Phelps 1925) and measure the amount of DO that will be required for each 1000 lb/day of BOD loading at each discharge point along the river. The inputs to the Streeter Phelps model those were required for each source-receptor pair included the flow, the travel time, the de-oxygenation and the re-aeration rate coefficient, and the BOD loading at the discharge locations. The functional relationship for the transfer coefficient model was thus of the form:

$$d_{ij} = \frac{L_i K^i{}_1}{Qj\left(K^{ij}{}_2 - K^i{}_1\right)}\left[e^{-K^i{}_1 t_{ij}} - e^{-K^{ij}{}_2 t_{ij}}\right] \quad (1)$$

where, d_{ij} = DO transfer coefficient; Qj = flow at the receptor location; t_{ij} = travel time from the discharge to receptor point; $K^{i}{}_{1}$ = deoxygenation rate coefficient; $K^{ij}{}_{2}$ = re-aeration rate coefficient; and L_i = BOD loading rate at the discharge location. The data for average values of deoxygenation rate coefficient and re-aeration rate coefficient for different river segments were adapted from Ahmed and Mohammed (1988) as shown in Table 3 and the calculated values of DO transfer coefficients are given in Table 4.

Estimation of BOD Abatement Costs

At present condition, the sources which cause the discharge of BOD through the points near Rayerbazar and Shahidnagar do not have at all any treatment facility, while among the sources which cause the discharge of BOD through the point near Pagla have a huge sewage treatment plant (PSTP) (capacity to provide tertiary level of treatment at a rate of up to 120,000 m^3/day) for BOD removal (Amin et al. 1998).

Table 3. Average values of deoxygenation rate coefficient, $K^{i}{}_{1}$ and re-aeration rate coefficient, $K^{ij}{}_{2}$ for different river segments

River segments between station nos.	1-2	1-3	1-5	1-7	4-5	4-7	6-7
Deoxygenation rate coefficient, $K^{i}{}_{1}$ (day^{-1})	0.262	0.23	0.256	0.136	0.256	0.171	0.136
Re-aeration rate coefficient $K^{ij}{}_{2}$ (day^{-1})	0.332	0.245	0.337	0.65	0.337	0.49	0.65

Adapted from: Ahmed and Mohammed 1988

Table 4. Dissolved Oxygen transfer coefficients[a], d_{ij}

Discharge points	*Receptor points of measurement*			
	Kamrangirchar	Keraniganj	Chadnighat	Hariharpara
	Distance from Bashila bridge(km)			
	5.0	8.0	11.5	17.5
Rayerbazar	0.0687	0.0823	0.0391	0.0057
Shahidnagar	-	-	0.0753	0.0336
Pagla	-	-	-	0.0044

[a] increase in DO (mg/L) at receptor points resulting from decrease of BOD (per1000 lbs/day) from discharge points

However, a considerable amount of BOD is still discharged from this point which is generated from other domestic and industrial sources. In this regard, data were collected through personal communication with the professional Environmental Engineers in Bangladesh. Engineering estimation (using the information provided by the India Water Portal 2009 and Eckenfelder 1970) was performed for different levels of BOD abatement costs in three different discharge points. Table 5 provides the characteristics which were used for estimating the total abatement costs for BOD removal at different discharge points through adopting different mechanisms. It is worth mentioning here that in this analysis at Rayerbazar and Shahidnagar two new sewage treatment plants have been proposed while in case of Pagla it was assumed and estimated that the excess amount of BOD load (apart from the effluent of PSTP) could be treated in the existing PSTP. The estimated total abatement costs (TAC) of BOD from the three discharge points are shown in Figure 2. In this case the total abatement cost functions are assumed to be quadratic, which implies linear marginal abatement cost (MAC) functions. The abatement cost functions were calculated through the regression analysis of the square values of BOD removed and the abatement costs. Thus the TAC that each source would have to incur to reduce the amount of BOD in the discharged effluent is estimated as:

Rayerbazar: $TAC_1 = 4.89\, R_1^2$, R_1 is BOD abated at Rayerbazar

Shahidnagar: $TAC_2 = 2.64\, R_2^2$, R_2 is BOD abated at Shahidnagar

Pagla: $TAC_3 = 38.12\, R_3^2$, R_3 is BOD abated at Pagla

Spreadsheet Simulation (Model Development)

The water quality spreadsheet for this study is developed in Excel modified from the concept originally developed by Dorfman and Jacoby (1972). As mentioned before, the main purpose of this study is to use this created spreadsheet to simulate the effects of three types of management strategies as mentioned before, which have been designed to reduce emissions of BOD and subsequently to increase the DO concentration, thereby improving water quality and reducing environmental damages. The spreadsheet has been set up so that the user should find the solutions by trial and error process. Alternatively, the user could use the 'Solver' tool in EXCEL, to find a solution. A spreadsheet is ideal for this process because the entire worksheet and also the graphs are recalculated each time an entry is changed. The user can move the cursor across various cells to examine the formulas used to make the calculations. The spreadsheet can be further modified according to user's specific needs. The spreadsheet is arranged in three parts to analyse the three different management strategies.

The first part is for analysing the uniform reduction strategy and is designed to examine the effect of a proportional reduction in BOD discharge from each of the three sources and the consequent abatement (treatment) cost. The objective of a uniform reduction strategy is to increase the minimum water quality reading in the river from the current undesirable level (U) to higher water quality classes (D, C, B, and ultimately A). This is done by implementing a strategy that mandates a uniform proportional reduction of

Table 5. Characteristics for estimating the total abatement costs for BOD removal

	Discharge points		
	Rayerbazar (Conventional)	Shahidnagar (Mixed Bed Biological Reactor)	Pagla (Existing plant)
Treatment levels	Pretreatment (screening)	Pretreatment (screening)	Pretreatment (screening)
	Primary plus pretreatment (Screeing + primary clarifiers)	Primary plus pretreatment (Screeing + primary clarifiers)	Primary plus pretreatment (Screeing + primary clarifiers)
	Pretreatment plus Primary plus low efficiency secondary (Screeing + primary clarifiers+ trickling filter)	Pretreatment plus Primary plus low efficiency secondary (Screeing + primary clarifiers+ activated sludge process)	Pretreatment plus Primary plus low efficiency secondary (Screeing + primary clarifiers+ trickling filter)
	Pretreatment plus Primary plus high efficiency secondary (Screeing + primary clarifiers+ trickling filter+ Biological Aerated Filter)	Pretreatment plus Primary plus high efficiency secondary (Screeing + primary clarifiers+ activated sludge process+ Moving Bed Biological Reactor)	-
	Pretreatment plus Primary plus high efficiency secondary plus tertiary (Screeing + primary clarifiers+ trickling filter+ Biological Aerated Filter+lagooning+ chlorination)	Pretreatment plus Primary plus high efficiency secondary plus tertiary (Screeing + primary clarifiers+ activated sludge process+ Moving Bed Biological Reactor+ sand filtration + chlorination)	Pretreatment plus Primary plus low efficiency secondary plus tertiary (Screeing + primary clarifiers+ trickling filter + lagooning + chlorination)

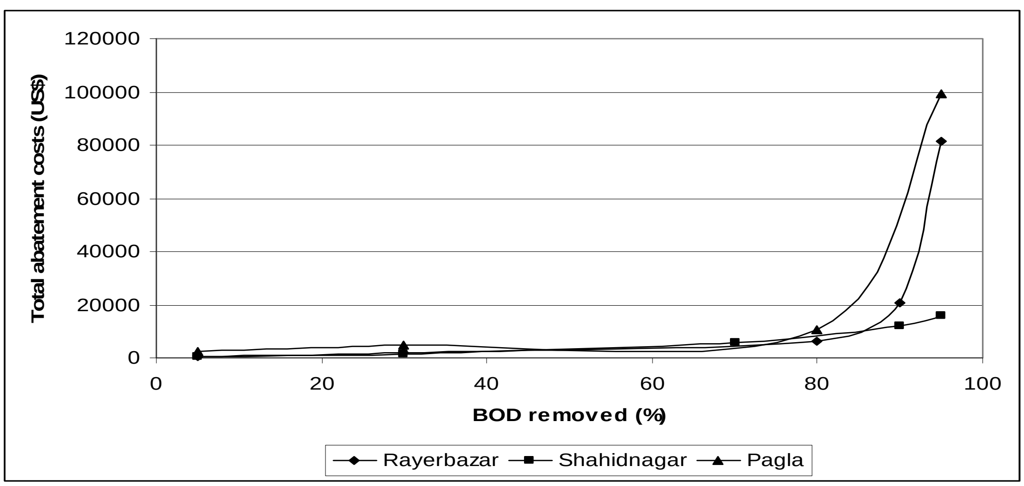


Figure 2. Total abatement costs at different discharge points

discharges across all sources. The spreadsheet calculation begins with a number between 0 and 1 which represent the fractional reduction in BOD discharge (e.g. 0.4 means a 40% reduction of discharge at each source). This translates into quantity of BOD abated by each source and the quantity of unabated BOD which appears in the subsequent columns of the spreadsheet. The user should vary (increase or decrease) the initial number entered (again has to be between 0 and 1) and observe how the resulting water quality changes by looking at the bar graph (which shows the level of water quality) provided at the end of part one. If the desired minimum level of water quality is D, then the required uniform reduction can be determined by trial and error (or alternatively by using the 'goal seek' or the 'solver' tools in EXCEL). For the minimum level of D, it was found that a uniform reduction of 0.415 (or proportional rollback of 41.5%) is required. The same can be done for each of the other water quality classes (results for all water quality levels are provided in Appendix 3). The abatement cost information is displayed in the last column for each of these required uniform reductions. This value should be used in comparing and evaluating alternative pollution management instruments. In general, the lower this value, the more effective is the management instrument.

The second part of the spreadsheet is for the analysis of uniform emission charges. Under this strategy, the sources are held liable for their emissions, and they have to pay a fee (or a levy, a tax) for each unit of pollutant (BOD) discharged. This creates incentives for the sources to reduce their BOD discharges, and to reduce their pollution tax liability. This means that each source would abate (or reduce its BOD discharge) as long as the marginal abatement cost (MAC) for abating an additional unit of BOD is less than the rate at which the tax is charged. This behaviour of the discharge points is captured by the following equations:

At Rayerbazar, $MAC_1 = 2*4.89 R_1 = MTR$; or $R_1 = MTR/ 2*4.89 = MTR/9.78$

At Shahidnagar, $MAC_2 = 2* 2.64 R_2 = MTR$; or $R_2 = MTR/ 2*2.64 = MTR/5.28$

At Pagla, $MAC_3 = 2* 38.12 R_3 = MTR$; or $R_3 = MTR/ 2*38.12 = MTR/76.24$

where $R_{(1,2,3)}$ denotes the reduction of BOD at each discharge point and MTR denotes the marginal tax rate (the marginal Pigovian fee, or charge). The =MINA() function in EXCEL is being used to ensure that the amount of abatement cannot exceed the amount which was originally discharged. The function is used to limit the amount of abatement as =MINA(original discharge, MTR/9.78). The appropriate formulas for the other sources have also been entered in the respective cells. By entering a MTR (or as used in the spreadsheet an 'Emission Charge'), the user can simulate the response of the sources, and will be able to determine the tax rate necessary to generate reduction in BOD discharges to meet the desired water quality targets. The user should now observe the resulting water quality levels, and in the associated bar graph. Then the emission charge need to be increased or decreased until the minimum charge (within $100 precision) that will raise all water quality levels to a minimum level of grade D. The process was repeated to determine the minimum emission charge necessary to generate the minimum water quality for use levels C, B, and A. All the results of the simulation exercise are provided in Appendix 3.

Finally, the third part is for the analysis of non-uniform ambient based emission permits, which involves two sub-parts. The first step uses a nonlinear programming approach to determine the minimum of the sum of costs of abatement and damages associated with the desired minimum water quality. The second step makes use of the Lagrange multipliers[7] (shadow values) to simulate the value of ambient permit prices that will deliver an abatement outcome consistent with the minimum abatement cost. The purpose here is to find the least cost combination of abatement by the three sources that will meet water quality limits at each of the four points of measurements. Conceptually this involves solving the following problem with four water quality constraints:

$$\min_{A_1, A_2, A_3} TAC_1 (A_1) + TAC_2 (A_2) + TAC_3 (A_3)$$

Subject to

$$109 = A_1 + BOD_1$$
$$78.7 = A_2 + BOD_2$$
$$47.7 = A_3 + BOD_3$$

(Initial emissions = abated + unabated discharges at each source)

where, $A_{(i)}$ are the quantities of abatement at each discharge point (i = 1, 2, 3).

Let DO_j be the desired minimum water quality at each receptor point (j = 1, 2, 3, 4). The additional constraints to the above problem pertaining to water quality at each of the four receptor points, given the previously described transfer coefficients are as follows:

$$8 = DO_1 + 0.0687 * BOD_1$$
$$8 = DO_2 + 0.0823 * BOD_1$$
$$8 = DO_3 + 0.0391 * BOD_1 + 0.0753 * BOD_2$$
$$8 = DO_4 + 0.0057 * BOD_1 + 0.0336 * BOD_2 + 0.0044 * BOD_3$$

If a uniform minimum water quality level is specified for all receptor points then $DO_1 = DO_2 = DO_3 = DO_4 = DO$. The problem can be solved as a constrained optimisation by differentiating with respect to, and then solving for the three abatement variables A_1, A_2, A_3 and the seven Lagrange variables associated with the constraints described above. This involves solving 10 equations in 10 unknown variables:

$$\text{Min } L (A_1, A_2, A_3, \lambda_1, \lambda_2, \lambda_3, \lambda_{r1}, \lambda_{r2}, \lambda_{r3}, \lambda_{r4}) =$$

$$TAC_1 + TAC_2 + TAC_3$$
$$+ \lambda_1(109.0 - A_1 - BOD_1) \quad \leftarrow \text{Source 1 discharges}$$
$$+ \lambda_2(78.7 - A_2 - BOD_2) \quad \leftarrow \text{Source 2 discharges}$$
$$+ \lambda_3(47.7 - A_3 - BOD_3) \quad \leftarrow \text{Source 3 discharges}$$
$$+\lambda_{r1} [8 - DO - \sum_{i=1}^{3} a_{i1}(BOD_i)] \quad \leftarrow \text{Receptor 1 DO}$$
$$+\lambda_{r2} [8 - DO - \sum_{i=1}^{3} a_{i2}(BOD_i)] \quad \leftarrow \text{Receptor 2 DO}$$
$$+\lambda_{r3} [8 - DO - \sum_{i=1}^{3} a_{i3}(BOD_i)] \quad \leftarrow \text{Receptor 3 DO}$$

[7] In mathematical optimization, the method of Lagrange multipliers (named after Joseph Louis Lagrange) provides a strategy for finding the maximum/minimum of a function subject to constraints (Hazell and Norton 1986).

$$+\lambda_{r4}\left[8 - DO - \sum_{i=1}^{3} a_{i4}(BOD_i)\right] \quad \leftarrow \text{Receptor 4 DO}$$

Where, L is the amount of BOD removed; TAC_i is the total abatement cost function for the i^{th} source; λ_1, λ_2, λ_3, are the Lagrange multipliers that can be interpreted as marginal abatement cost (MAC) at each of the sources; λ_{rj} are the Lagrange multipliers that can be interpreted as ambient permit prices at receptor points j = 1, 2, 3, 4; DO is a uniform minimum level of dissolved oxygen for all receptors. However, it may be desirable to exceed the minimum water quality at one or more points along the river so it is useful to solve the problem as a non-linear model (exact solution) or to obtain an approximate solution as a linear programming model. In EXCEL the nonlinear equation solver, which is built into the spreadsheet was used to find a solution to the non-linear programming and the solution values automatically appears in the sensitivity report. The solution values (+ve number) are the ambient permit prices at the receptor points which are again used in the first subpart of this analysis to get the remaining information on the BOD abated and the corresponding abatement costs.

STATE OF POLLUTION IN TERMS OF OXYGEN DEMANDING WASTES

The current study along with the previous studies (Ahmed and Mohammed 1988; Browder 1992; Kamal et al. 1999; Karn and Harda 2001; Alam 2002; Rahman and Hossain 2007) show the DO and the BOD values along the different locations of the river Buriganga (Figure 3 and 4) are remaining far beyond the acceptable levels. This also proves the decline of water quality in terms of oxygen demanding wastes in different sections along its 17.5 km winding course with mere existence of fish and other aquatic species in the river particularly during the dry season (November to April). Figure 3 also provides information that the worst condition of the river exist between the sections Kamrangirchar and Chadnighat, so the critical level of DO may also remain within this section.

The graphs (Figures 3 and 4) also indicate that the average values of DO and BOD at different points fluctuate over the years and do not follow a definite trend, however, the results prove that an alarming condition is prevailing in the river water quality during the dry season. Therefore, this phenomenon confirms that the current management system (CAC approach) for pollution control has completely failed to stop such degradation of this river. These empirical values justify the necessity of application of alternate management strategy for reduction of BOD at the receptor points along the river Buriganga.

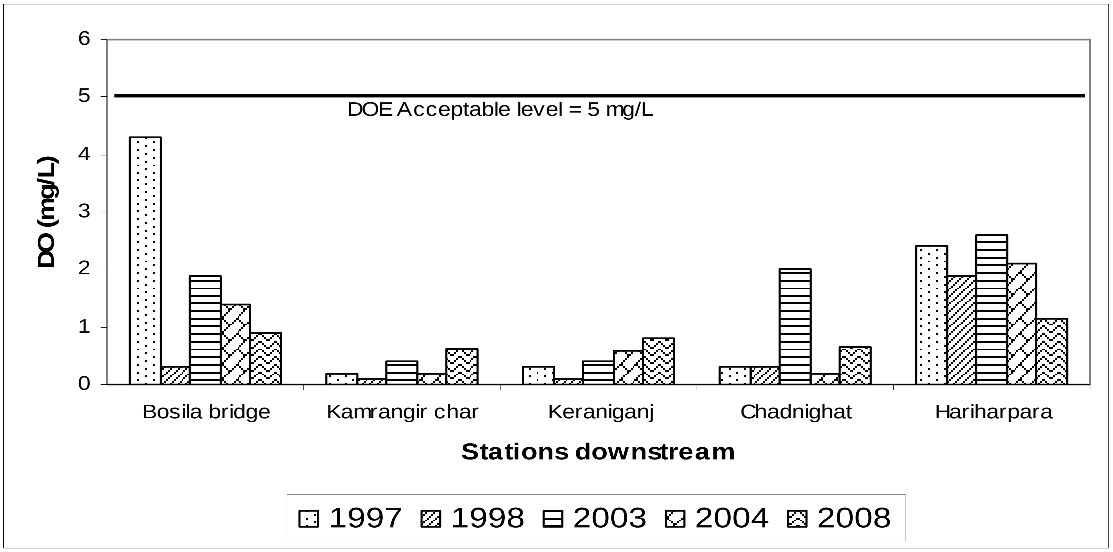


Figure 3. The trend of DO levels along the Buriganga River during dry season in different years

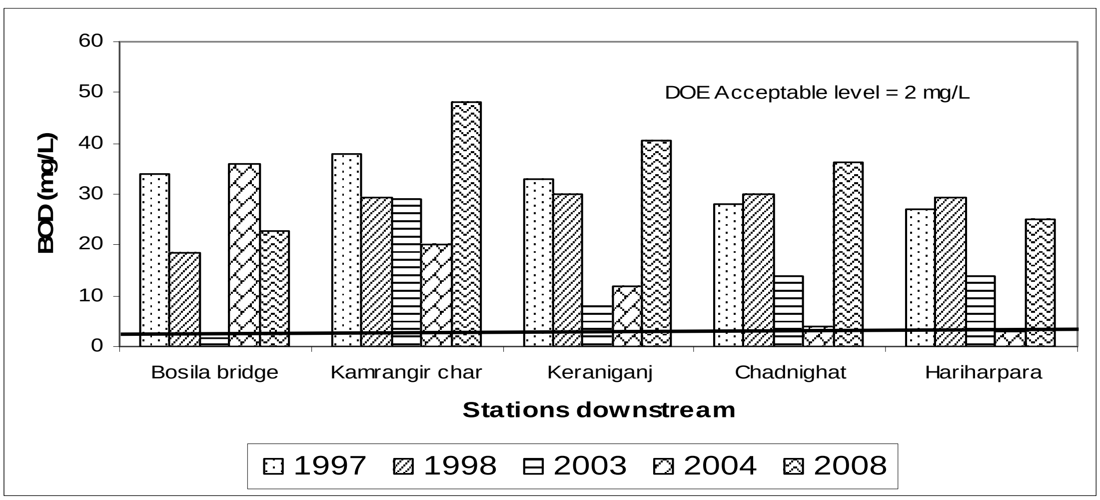


Figure 4. The trend of BOD levels along the Buriganga River during dry season in different years

EVALUATION OF ALTERNATIVE STRATEGIES

As explained in earlier sections, in this study an economic cost analysis among different alternate strategies has been done for achieving different water quality levels (in terms of DO) along the river. The results are displayed in Table 6.

Table 6. Summary results from Simulation exercise for exploration of alternative decisions

Water quality class	Strategy	Charge / Permit price (US$ / 000 BOD)	Total abatement costs / day (US$)	Treatment level at sources (% BOD removed)		
				Rayerbazar	Shahidnagar	Pagla
D	Uniform reduction in emissions	-	$27,760	41.5	41.5	41.5
	Uniform emissions charges	$355	$19,204	33	85	10
	Ambient permit system	At Keraniganj = $3074 At Chadnighat = $2589	$10,016	33	47	0
C	Uniform reduction in emissions	-	$50,547	56	56	56
	Uniform emissions charges	$535	$32,845	50	100	15
	Ambient permit system	At Keraniganj = $4891 At Chadnighat = $3321	$20,422	50	60	0
B	Uniform reduction in emissions	-	$81,253	71	71	71
	Uniform emissions charges	$710	$45,412	67	100	19
	Ambient permit system	At Keraniganj = $6709 At Chadnighat = $4054	$34,653	67	73	0
A	Uniform reduction in emissions	-	$132,013	89	100	26
	Uniform emissions charges	$950	$68,393	89.2	100	100
	Ambient permit system	At Keraniganj = $9132 At Chadnighat = $5031	$59,578	89	91	0

The analysis proves that in each type of water quality levels and within the three different type of strategies, the ambient permit system always becomes the most cost effective solution followed by the uniform emissions charges and uniform reduction in emissions. For example, to achieve a water class B by the application of ambient permit system, the total abatement costs will the US$34,653 while it will be US$45,412 (31% higher) and US$ 81,253 (134% higher) if the uniform emissions charges and the uniform reduction in emissions are applied respectively. The similar situation exists for all other water quality levels. Moreover, this analytical technique also provides the minimum values for the charge or the permit price to be applied for achieving a given water quality target.

These values and the state of water quality information indicates the ineffectiveness of the current CAC mechanism (uniform reduction in emissions) and justifies the necessity of applying alternate EI based management system for reduction of BOD in the river Buriganga, particularly for the dry season. However, as mentioned earlier, for effective implementation of any such alternate strategy, further detailed study particularly on the transactions costs is necessary.

CONCLUSION

This study has developed a spreadsheet based analytical technique for evaluating the environmental and economic effectiveness of alternate management strategies for reduction of BOD along the river Buriganga. It has been empirically proved and concluded that if the transactions costs are kept low, the EI based management strategies would become more effective than the CAC based management strategies for controlling the BOD in the river Buriganga.

REFERENCES

Afsah, S., Laplante, B. and Wheeler, D. (1996) *Controlling Industrial Pollution: a new paradigm*, Policy Research Working Paper No. 1672, The World Bank.

Ahmed, M. F. and Mohammed, K.N. (1988) ‘Pollution effects of effluent discharges from Dhaka City on the river Buriganga’, in T. Pansward (ed.), *Pollution Control in Developing Countries*, pp 123-129, Pergamon Press, Thailand.

Ahmed , M. F. and Rahman, M. M. (2007) *Water Supply and Sanitation: rural and low income urban communities*, ITN-Bangladesh.

Alam, K. (2002) ‘Valuing the cleanup of the Buriganga River’, in F. Ahmed (ed.), *Bangladesh Environment 2002*, pp 978-991, Bangladesh Poribesh Andolon, Dhaka.

—— (2008) ‘Cost-benefit analysis of restoring Buriganga river, Bangladesh’, *Water Resources Development*, vol. 24, no.4, pp 593-607.

Amin, A.F.M.S., Shamsuddin, S.A.J. and Alam, M.M. (1998) ‘Optimisation of sewage treatment process at Pagla’, 24th WEDC conference, Islamabad, Pakistan.

APHA (American Public Health Association) (2005) *Standard Methods for the Examination of Water and Wastewater*, 21st edition, Washington DC.

Asolekar, S.R. (2002) 'Greening of Industries and Communities', in Lead India (ed.), *Rio, Johannesburg and Beyond: India's Progress in Sustainable Development*, Chapter 7, Orient Longman, Hyderabad, India.

Austin, D. (1999) 'Economic Instruments for Pollution Control and Prevention: a brief overview', World Resources Institute, http://pdf.wri.org/incentives_austin.pdf (accessed on 16/06/2008).

BKH Consulting Engineers (1995) 'Industrial pollution control management, Bangladesh', ADB TA 1769-BAN, Final Report-Phase 1, The Asian Development Bank, Dhaka.

Browder, G. J. (1992) 'Final report for water quality management task', ADB TA 1104-BAN, National Environmental Monitoring and Pollution Control Project, The Asian Development Bank, Dhaka.

Dattagupta, N. (2004) 'Challenges in hazardous waste minimization', Proceeding of workshop on Hazardous Waste-Strategies for Minimization, USEFI, December 9-11, Ahmedabad.

Delmas, M.A. (2002) 'The diffusion of environmental management standards in Europe and United States: an institutional perspective', *Policy Sciences*, vol. 35, No. 1 (March), pp. 91-119, Springer.

Dorfman, R. and Jacoby, H.D. (1972) 'An illustrative model of river basin pollution control', in R. Dorfman, H.D. Jacoby and H.A. Thomas Jr. (eds), *Models for Managing Regional Water Quality*, Harvard University Press, Cambridge.

DWASA (Dhaka Water Supply and Sewerage Authority) (1998) 'Dhaka Water Resources Management Programme', Fourth Dhaka Water Supply Project, Final Report, Govt. of the People's Republic of Bangladesh.

Eckenfelder, W.W.Jr. (1970) *Water Quality Engineering for Practicing Engineers*, Cahners Books, Massachusetts.

EDA (1999) *Environmental Laws in Bangladesh*, Environment and Development Alliance, Dhaka.

Eskeland, G.S. and Jimenez, E. (1992) 'Policy Instruments for Pollution Control in Developing Countries', *The World Bank Research Observer*, vol. 7, No. 2, pp. 145-69, Oxford University Press, UK.

Farooque, M. and Hasan, S.R. (1996) *Laws Regulating Environment in Bangladesh*, Bangladesh Environmental Lawyers Association (BELA), Dhaka.

FCE (Fenner Conference on the Environment) (1994) *Sustainability: Principles to Practice*, Background Papers, 13-16 November, Department of Environment, Sport and territories, Canberra.

Field, B.C. (1994) *Environmental Economics: An Introduction*, McGraw-Hill, New York.

Gore, J.A. (2007) 'Discharge Measurements and Streamflow Analysis', in F.R. Hauer and G.A. Lamberti (eds.), *Methods in Stream Ecology*, 2nd edition, Academic Press, USA.

Hazell P.B.R. and Norton, R.D. (1986) *Mathematical Programming for Economic Analysis in Agriculture*, Macmillan Publishing Company, New York.

India Water Portal (2009) 'Safe, sustainable water for all', http://www.indiawaterportal.org/ (accessed on 12 July 2009).

Jaeger, W.K. (2005) *Environmental Economics for Tree Huggers and Other Skeptics*, Island Press, Washington.

JICA (Japan International Cooperation Agency) (1991) 'Master plan for greater Dhaka protection project', FAP 8A supporting report, Government of Bangladesh.

Kamal, M.M., Malmgren-Hansen, A. and Badruzzaman, A.B.M. (1999) 'Assessment of pollution of the river Buriganga, Bangladesh, using a water quality model', *Water Science Technology*, vol. 40, no. 2, pp129-36.

Karn, S.K. and Harda, H. (2001) 'Surface water pollution in three urban territories of Nepal, India and Bangladesh', *Environmental Management*, vol. 28, no.4, pp 483-496, Springer-Verlag New York Inc.

Kathuria, V. (2006) 'Controlling water pollution in developing and transition countries—lessons from three successful cases', Journal of Environmental Management, vol. 78, pp. 405-426, Elsevier.

Kolstad, C.D. (2000) *Environmental Economics,* Oxford University Press, New York.

Kraemer, R.A. (1995) *The Effectiveness and Efficiency of Water Effluent Charge Systems: case study on Germany*, ENV/EPOC/GEEI (95) 12 restricted, Paris: OECD.

Krishnamoorthy, B. (2005) *Environmental Management*, Prentice Hall of India Private Ltd, New Delhi.

Larsen, H. and Ipsen, N. H. (1997) 'Framework for Water Pollution Control', in R. Helmer and I. Hespanhol (eds), *Water Pollution Control: a guide to the use of water quality management*, chapter 10, WHO/UNEP.

Magumdar, T.K. (2005) 'Assessment of water quality of the peripheral river system around Dhaka City', M. Engg. Thesis, Bangladesh University of Engineering and Technology, Dhaka.

Masters, G. (2004) *Introduction to Environmental Engineering and Science*, Prentice Hall of India Private Ltd., New Delhi.

Oates, W.E., Portney, P.R. and McGartland, A.M. (1989) *The Net Benefits of Incentive-Based Regulation: The Case of Environmental Standard-Setting in the Real World*, Discussion Paper CRM 89-03.

Pearce, D. and Turner, K. (1990) *Economics of Natural Resources and the Environment*, Harvester Wheatsheaf, Hertfordshire, U.K.

Pigou, A.C. (1962) *The Economics of Welfare*, 4th Ed., McMillan, London.

Pu, Q. (2003) 'Integrated Strategies to Control Industrial Water Pollution in the Yangtze of China', Paper presented at International Conference of GIS and Remote Sensing in Hydrology, Water Resources and Environment, 16 September 2003, China, http://cres.anu.edu.au/people/pqh1.pdf (accessed on 20/03/2007).

Rahman, S. and Hossain, F. (2008) 'Spatial assessment of water quality in peripheral rivers of Dhaka City for optimal relocation of water intake point', *Water Resources Management*, vol. 22, pp. 377-391.

Rahman, M. R. and Rana, M. Y. (1996) 'Pollution assimilation capacity of Buriganga River', *Journal of Civil Engineering*, vol. CE 24, no. 1, The Institute of Engineers, Bangladesh.

Rathi, A.K.A. (2003) 'Promotion of Cleaner Production for Industrial Pollution Abatement in Gujrat, India', *Journal of Cleaner Production*, vol.11, No.5 (August), pp. 583-90, Elsevier Ltd.

Sperling, M.V. (2007) *Biological Wastewater Treatment: wastewater characteristics, treatment and disposal*, volume 1, IWA Publishing, UK.

Stavins, R.N. (1995) 'Transactions costs and tradable permits', *Journal of Environmental Economics and Management*, vol. 29, pp. 133-148.

Streeter, H.W. and Phelps, H.B. (1925) 'A study of the pollution and natural purification on the Ohio River-III', *Public Health Bulletin*, vol. 146, US Department of the Treasury, Washington.

SWMC (1995) 'Water quality pilot modelling of the river Buriganga', Final Report, Surface Water Simulation Modelling Programme-Phase III, Surface Water Modelling Centre, Dhaka.

Tietenberg, T. (2006) *Environmental and Natural Resource Economics*, 7th edition, Addison Wesley, Pearson Education, Inc., New York.

UNDSD (United Nations Division for Sustainable Development) (1992) *Agenda 21*, United Nations Conference on Environment and Development, Rio de Janeiro, Brazil.

Wikipedia (2009) 'Dhaka', http://en.wikipedia.org/wiki/Dhaka (accessed on 20 September 2009).

BWDB (Bangladesh Water Development Board) (2004) 'Feasibility and mathematical model study of approaching and investigating strategy for rehabilitating the Buriganga-Turag-Shitalakhya river system and augmentation for dry season flow in the Buriganga river', vol. 1: Main Report, Govt. of the People's Republic of Bangladesh.

World Bank (2000) *Greening Industry: new roles for communities, markets and governments*, Oxford University Press, New York.

APPENDIX 1. INFORMATION ON DISCHARGE POINTS OF WASTEWATER

Discharge points	Description/Location	Wastewater type	Detailed information on wastewater source and drainage area
Near Rayerbazar sluice gate	Drains tannery waste of Hazaribagh along with domestic wastes of Rayerbazar, Nimtala, Sultanganj, Zigatola, Nawabganj and west Dhanmondi	Tannery wastewater	196 tanneries Total production[1] = 83,000 tons/yr
		Municipal wastewater	Area[2] = 17.6 km^2
Near Shahidnagar	Drains waste water (unsewered or partially sewered) from Pilkhana, Enayetganj, Azimpur, Nawabganj and adjoining areas	Municipal wastewater	Area[2] = 17.7 km^2
Near Pagla Sewage Treatment Plant (PSTP) effluent discharge point	Discharges treated sewage from PSTP, Industrial wastes from Pagla, Shyampur and Postogola	Treated sewage water	Level of treatment = Secondary treatment (primary sedimentation tank and facultative lagoon) Flow of treated wastewater[3] = 38,000 m^3/day
		Municipal wastewater	Area[2] = 7.25 km^2
		Textile industry wastewater	2 textiles Total production[1] = 250 tons/yr
		Iron and Steel industry wastewater	8 iron and steel industries Total production[1] = 10,000 tons/yr

[1] BKH 1995
[2] Adapted from Browder 1992 and Rahman and Rana 1996
[3]Amin et al. 1998

APPENDIX 2. ESTIMATION OF BOD LOADINGS AT THE DISCHARGE POINTS BY DRY METHOD

Discharge points	Drainage area[1] (km^2)	Total Population[2]	Population unsewered[3]	Industry	Municipal wastewater flow[4] (m3/sec)	Waste water flow from tannery/textile/Iron/PSTP[5] (m3/sec)	BOD load from sewage[6] (tons/d)	BOD load from tannery/textile/PSTP [7] (tons/d)	Total flow of waste water	Total BOD load (tons/d)	Total BOD load (000 lb/d)
Rayerbazar	17.6	809,600	647,680	tannery	0.750	0.18	32.38	17.6	0.930	49.984	109.96
Shahidnagar	17.7	814,200	651,360	-	0.754	4.75	32.56	-	0.754	32.568	71.65
Pagla	7.25	333,500	266,800	textile+iron+ PSTP	0.309	1.14	13.34	4.75+1.6	1.449	19.69	43.32

[1] Adapted from Browder 1992 and Rahman and Rana 1996
[2] Population density of Dhaka City = 46,000/km^2 (Wikipedia 2009)
[3] Eighty percent of total population (as the information provided by DWASA official)
[4] Average sewage flow rate = 0.1 m^3/capita/day (Ahmed and Rahman 2007)
[5] BKH 1995
[6] Sewage load = 50 gm/capita/day (Sperling 2007)
[7] Adapted from Rahman and Rana 1996

APPENDIX 3. RESULTS OF EXCEL SIMULATION ANALYSIS FOR THE THREE DIFFERENT POLLUTION MANAGEMENT STRATEGIES

Strategy 1: UNIFORM REDUCTION IN EMISSIONS

Source	Minimum Water Quality = D			
	Proportion by which emissions are reduced (%)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	41.5	63.8	$10,006	$442
Shahidnagar	41.5	46.0	$2,816	$172
Pagla	41.5	27.9	$14,938	$1,509
Total		137.7	$27,760	
Source	Minimum Water Quality = C			
	Proportion by which emissions are reduced (%)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	56	48.0	$18,220	$597
Shahidnagar	56	34.6	$5,128	$233
Pagla	56	21.0	$27,200	$2,037
Total		103.6	$50,547	
Source	Minimum Water Quality = B			
	Proportion by which emissions are reduced (%)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	71	31.6	$29,287	$757
Shahidnagar	71	22.8	$8,243	$295
Pagla	71	13.8	$43,723	$2,582
Total		68.3	$81,253	
Source	Minimum Water Quality = A			
	Proportion by which emissions are reduced (%)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	90.5	10.4	$47,584	$965
Shahidnagar	90.5	7.5	$13,392	$376
Pagla	90.5	4.5	$71,037	$3,291
Total		22.4	$132,013	

Strategy 2: UNIFORM EMISSIONS CHARGES

Source	Minimum Water Quality = D Emission charge = US$355 /000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	36.3	72.7	$6,443	$355
Shahidnagar	67.2	11.4	$11,934	$355
Pagla	4.7	43.0	$827	$355
Total	108.2	127.2	$19,204	

Source	Minimum Water Quality = C Emission charge = US$535 /000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	54.7	54.3	$14,633	$535
Shahidnagar	78.7	0	$616,334	$415
Pagla	7.0	40.7	$1,877	$535
Total	140.4	95	$32,845	

Source	Minimum Water Quality = B Emission charge = US$710/000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	72.6	36.4	$25,772	$710
Shahidnagar	78.7	0	$16,334	$415
Pagla	9.3	38.4	$3,306	$710
Total	160.6	74.8	$45,412	

Source	Minimum Water Quality = A Emission charge = US$950/000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	97.1	11.9	$46,140	$950
Shahidnagar	78.7	0	$16,334	$415
Pagla	12.5	35.2	$5,919	$950
Total	188.3	47.1	$68,393	

Strategy 3: AMBIENT PERMIT SYSTEM

Source	Minimum Water Quality = D Price of permit for BOD at Keraniganj = US$3,074 /000 lb BOD Price of permit for BOD at Chadnighat = US$2,589 /000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	36.2	72.8	$6,415	$354
Shahidnagar	36.9	41.7	$3,601	$195
Pagla	0	47.7	$0.0	$ 0
Total	73.2	162.2	$10,016	

Source	Minimum Water Quality = C Price of permit for BOD at Keraniganj = US$4,891 /000 lb BOD Price of permit for BOD at Chadnighat = US$3,321 /000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	54.4	54.6	$14,496	$532
Shahidnagar	47.4	31.3	$5,927	$250
Pagla	0	47.7	$0	$ 0
Total	101.8	133.5	$20,422	

Source	Minimum Water Quality = B Price of permit for BOD at Keraniganj = US$6,709 /000 lb BOD Price of permit for BOD at Chadnighat = US$4,054 /000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	72.7	36.3	$25,825	$711
Shahidnagar	57.8	20.8	$78,829	$305
Pagla	0	47.7	$ 0	$ 0
Total	130.5	104.8	$34,653	

Source	Minimum Water Quality = A Price of permit for BOD at Keraniganj = US$9,132 /000 lb BOD Price of permit for BOD at Chadnighat = US$5,031/000 lb BOD			
	Minimum additional abatement (000 lbs/day)	Remaining BOD (000 lbs/day)	Abatement costs	
			Total (US$/day)	Marginal (US$/ 000 lb BOD)
Rayerbazar	97.0	12	$45,983	$948
Shahidnagar	71.8	6.9	$13,596	$379
Pagla	0	47.7	0	0
Total	168.7	66.6	$59,578	